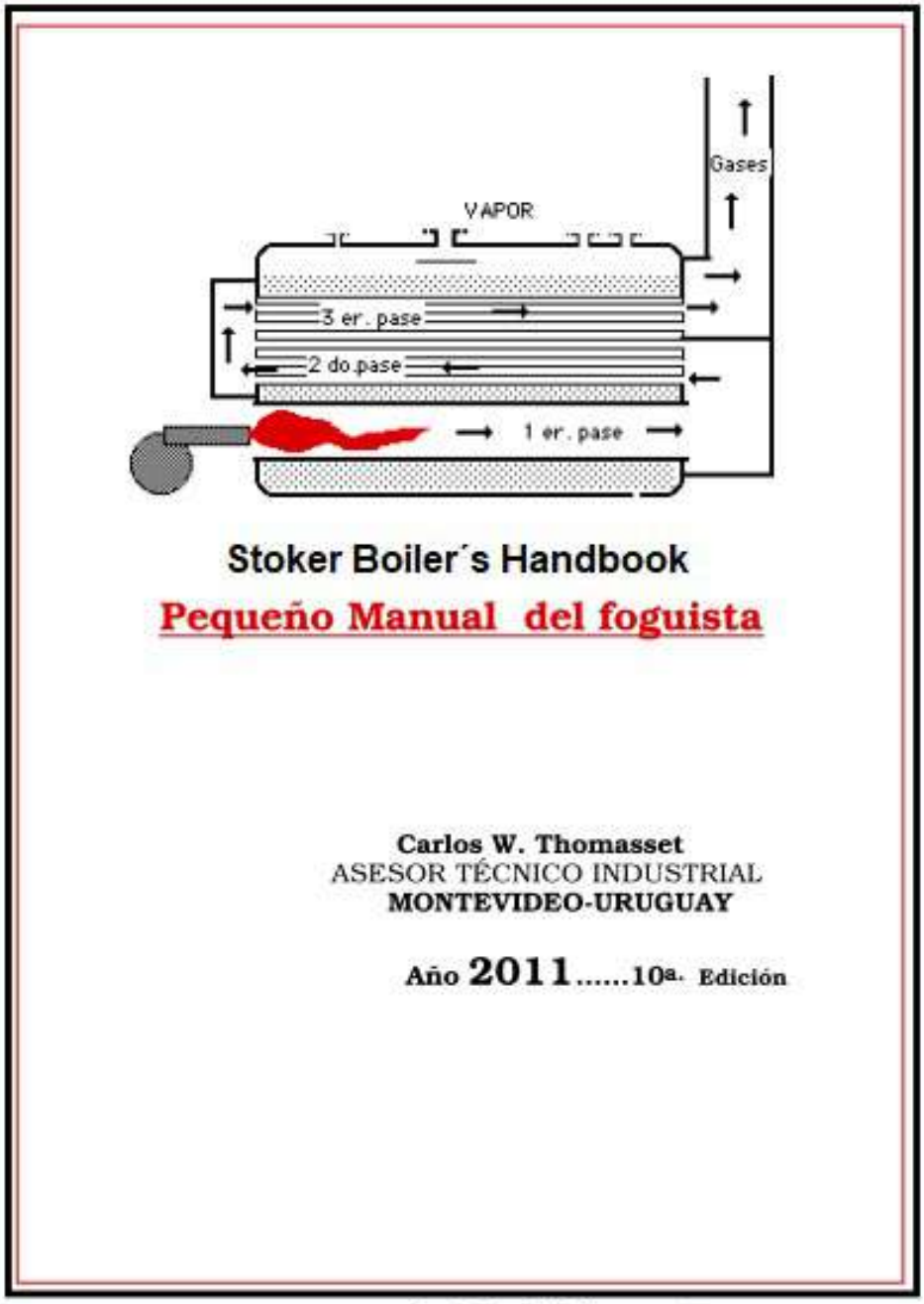
Stoker Boiler´s Handbook 2011, C.W.T. – INTRODUCTION



0 Carlos W. Thomasset

Today October 2025 and "Stoker Boiler´s Handbook" ("Pequeño Manual del Foguista") match 6000 views or downloads in archive.org

I think my father handbook deserve an english version translation, available to to everybody in the world. A practical handbook, boiler basic knowledge in operation to stokers and even to politechnic and academy enginners.

Pablo Juan Thomasset Trakalo, 31.10.2025

FOREWORD 1

This is a new version of the "Stoker Boiler´s Handbook" a tool developed by Carlos W. Thomasset that has been an invaluable resource for years, far exceeding its intended audience.

This Handbook possesses a rare virtue: in its theoretical foundations, while maintaining scientific rigor, it uses language understandable to all, yet upholds a level of sophistication that elevates the profession.

But what is most interesting, of immense value to both boilermakers and engineers, is the selfless transmission of practical knowledge included in this Handbook, which summarizes his life dedicated to the subject.

In every paragraph, in the advice or warning that may seem insignificant, is reflected the hard-won knowledge acquired through his extensive experience.

It is truly a reference source for everyone involved in the subject.

During my professional career in this field, there wasn't a significant problem I had to solve without discussing it with Carlos W. Thomasset and taking into account his insightful and unbiased opinions.
Because we view the profession and life with a similar ethical framework, we share a sincere friendship.

Likewise, I believe this Manual will be a friend to the reader.

Eng. Kurt Bauer, Montevideo, Uruguay, 2011

FOREWORD 2

The 10th edition, 2011, of the Little Stoker's Manual was written during the 2010-2011 oil crisis (the second oil crisis of the 21st century, following more than one crisis in the 20th century). In the previous edition (2008), we stated the same as in 2011: "This is yet another attempt to transmit practical and theoretical knowledge at a time when the price of oil is rising worldwide."

When we "burn" oil in the form of liquid fuels or natural gas to generate energy in the form of steam (both for heating products and for generating mechanical and electrical energy), we are expending chemical energy, which is the product of millions of years of accumulated solar energy in the form of biological "waste" on Earth.

Now, in just a few decades (perhaps in less than two centuries, much of which has already passed), we will consume them... It is our duty; we possess some of the knowledge, and we must be responsible, to prevent the "remnants" of this energy from being "squandered."

Humankind has not yet developed a truly "clean" energy alternative that meets all the needs of human society. Are we close or far from it? It's still unclear... In Uruguay, a country that is almost an energy desert, the only thing that has been achieved is covering a small part of its energy needs with hydroelectric dams (for electricity generation, provided it rains).

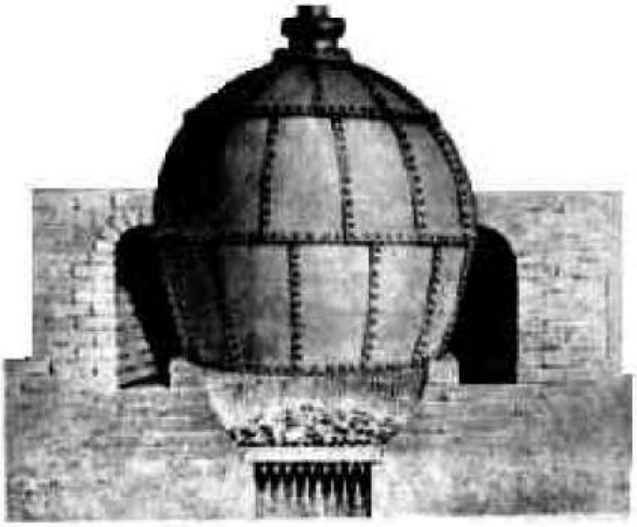
For now, another possible energy source is firewood, eucalyptus (both its specific consumption and any potential export waste), or agricultural byproducts (peels and other materials), for combustion in boilers. Other energy sources are either imported or will be a hope for the future....

This publication is not a book, it's a manual (intended as a working tool). Alternative fuels, such as firewood (eucalyptus) and other biomass, are the immediate solution for Uruguay, at least for generating steam and electricity in a combined cycle (combined generation).

Let's try to do things in the best way possible... and this is the spirit of this Little Manual. Everything we've said, we are experiencing firsthand, and we're still waiting for action. It's already 2011, and some efforts are being made to do something with biomass, wind energy, solar energy, and biofuels.

Carlos W. Thomasset, 2011

A brief history of boilers



caldera Haycock 1720

The history of boilers seems to lack a clear beginning. For many centuries, humankind has sought to harness the power of steam. Initially, this involved utilizing the properties of condensation, where atmospheric pressure actually performed the work of pressure as the steam condensed.

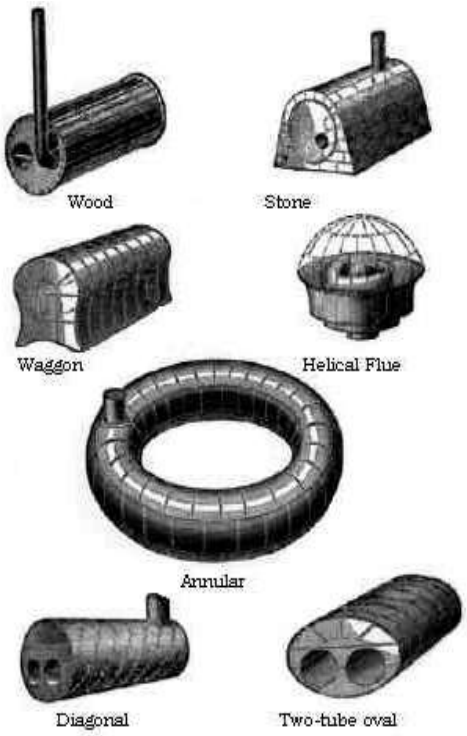
It can be said that until the end of the 18th century, boilers operated at such low pressures (barely 3 to 4 pounds per square inch, or 200-300 grams per square centimeter, or 2-3 meters of water column) that they simply displaced the air with the steam, then proceeded to cool the steam. The condensation created a "vacuum," allowing atmospheric pressure to do the work of moving a piston.

The lack of knowledge and materials was a natural limitation. Copper sheets, brass, cast iron, even wood and other materials were used in the construction. When creating the watertight seal between the plates that formed the boiler, there were so many leaks that, despite sealing it with a cardboard caulking or something similar, they then had to put elements in the water to act as "plugs" between the joints (even horse manure was put in the water!).

Let's look at a drawing of this type of boiler and even a photograph!

Fotografía tomada en 1938 caldera Haystack

This geometric shape seems quite reasonable for the time, but we'll see that there are other, more disparate shapes. There's a photograph taken in 1938 of a boiler similar to this type (found in Great Britain), which gives us an idea of what these boilers looked like. Getting to this point was quite an achievement.
Let's look at some more drawings of these early boilers from the 1700s... like the following:



Some of these low-pressure boilers, especially the last ones in the previous table, lasted until the beginning of the 20th century.

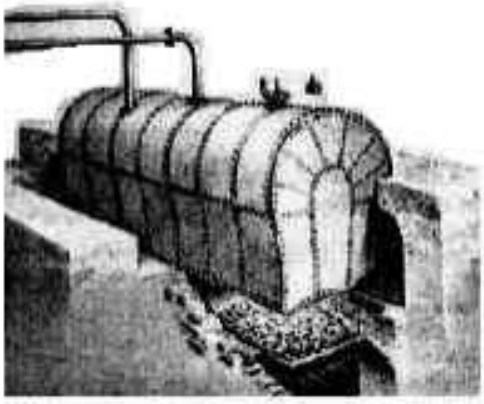
In Uruguay, at the Casablanca meatpacking plant in Paysandú, in the 1970s, they were still using Diagonal-type boilers with two combustion tubes and the combustion gas returning through the sides; burning wood, their efficiency barely reached 50%.
The risk and inefficiency (heat utilization) of these boilers, manufactured more by blacksmiths than by mechanics or specialized workshops, were so great that many people died operating them.

With the emergence of iron as sheet metal (iron foundries already existed, but "refined" iron, which could be mechanically worked, did not yet exist) in forged "plates," and with the need for operating energy in mines and factories, the first boilers with a real sense of heat utilization and with some safety features began to appear.

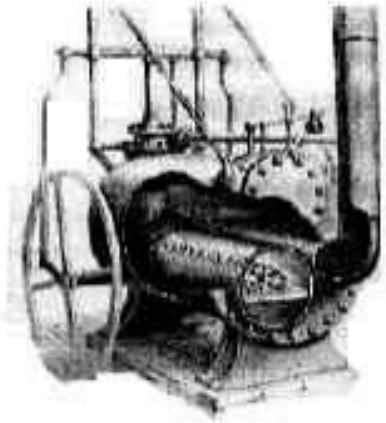
Modern boilers emerged with the dawn of the "industrial" era in European countries, especially Great Britain, Germany, and others, and in America (the United States).

The effort to convert heat energy into mechanical energy to replace the energy derived from humans, animals, wind, water, etc., was a constant objective for humankind.

First on land, particularly in mines, then in industry and railroads, in harvesters, etc., this led to the naval use of this new, usable power.
Perhaps the first fire-tube boiler based on these principles was Trevithick's in 1804.



Waggon 1768



Caldera Trevithick 1804

Comparing Mr. Trevithick's boiler of 1804 with a Waggon boiler of 1768, they are clearly worlds apart.

Improving the quality of materials, design, safety features, operation, etc., the 19th century would be the golden age of boilers, with reciprocating steam engines, as internal combustion engines would only appear at the end of the century and the beginning of the 20th.

At the end of the 19th and beginning of the 20th centuries, steam turbines would appear, powering large factories and steamships.
Among the problems with boilers in the 19th and early 20th centuries, the issue of water was very significant, as there was a great lack of knowledge about its management. Generally, the water available on site was used, which was often of the worst quality.

Little by little, the "engineers" or first "boilermen" acquired practical knowledge to improve the water's behavior in the boilers.

They used a wide variety of materials inside the boilers (from potatoes to sawdust, etc.) to prevent scale buildup. This resulted in removable sludge, which could be cleared by purging or, in many cases, by opening a lid or cap of the boiler after each shift to remove the accumulated sludge and then replacing the materials (potatoes, sawdust, etc.) before the next operation.

So many people died or were injured that, in both Great Britain and the United States, insurance companies pressured boiler manufacturers to implement improvements to prevent accidents. So much so, that even publications of that era dedicated sections to boiler accidents of the month.

In England, an insurance company had determined that in approximately 1862, a monthly report indicated that 202 boiler explosions had been recorded that month, resulting in 438 deaths and 476 serious injuries.

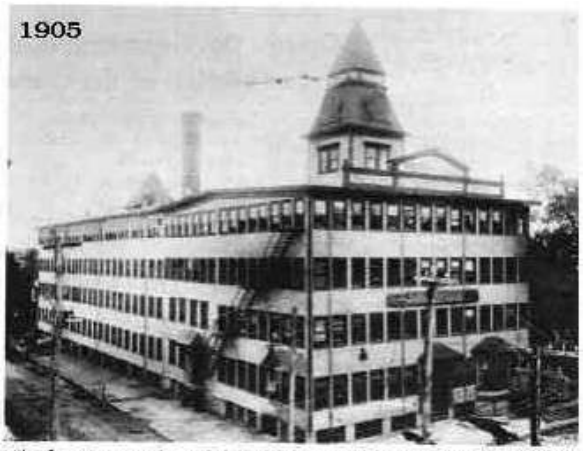
As the 19th century progressed, water-tube boilers appeared, offering greater safety as working pressure increased. They came to be called "explosive-proof."

But the entire 19th century was a true "battle" to achieve boilers with a degree of safety.

In 1866, a "Records of Boiler Explosions" report in Great Britain concluded that approximately 1,046 explosions had occurred, resulting in the deaths of 4,076 people and injuries to 2,903 (there were likely more unreported

incidents due to a lack of monitoring, reporting, or record-keeping).

In both Europe and the United States, associations of engineers, manufacturers, insurers, and others were formed. They became aware of the problem and established standards for the design, construction, operation, and inspection of boilers.



Fábrica de zapatos, de Brockton en Massachusetts, U.S.A.

For example, in the UNITED STATES, the following occurred:

It wasn't until the 1880s that ASME (American Society of Mechanical Engineers) was founded. This society of engineers would create standards for the manufacture of mechanical components, eventually leading to what would be called the Boiler & Pressure Vessel Code.

During these years, so many boiler accidents occurred that technical magazines, such as POWER MAGAZINE, had a section called:

"This Month's Accidents."

This led to boiler manufacturers meeting and creating ABMA (American Boiler Manufacturers Association) in 1888.

The combination of these associations with insurance companies (responsible for economic losses) in the event of serious disasters forced the need for these boiler codes or regulations.

One event highlighted this need.

In 1905, a shoe factory served as the catalyst for this situation of unsafe practices.

It was a "tremendous explosion" in Brockton, Massachusetts, where a shoe factory was practically destroyed, killing many people and injuring many more.

From this event onward, the idea of a code for boiler construction began to take shape, one that would include representatives from mechanical engineers, boiler manufacturers, and insurance companies.

This led to the creation in the state of Massachusetts of the first code for the construction, maintenance, and inspection of boilers with the force of law.

Then another state, Ohio, followed Massachusetts' example.

Now the conditions were right for the creation of the first national code. This took a few more years, with discussions, but in 1914, the Rules for the Construction of Stationary Boilers and for Allowable Working Pressures was created.

It was approved in 1915; it was an ASME code, in consultation with the ABMA. For it to have the force of law throughout the country, it was necessary to create what was called The American Uniform Boiler Law Society (formed in 1916).
Currently, the American code is called the ASME Boiler and Pressure Vessel Code.

Let's not forget that a simple compressed air container can be very

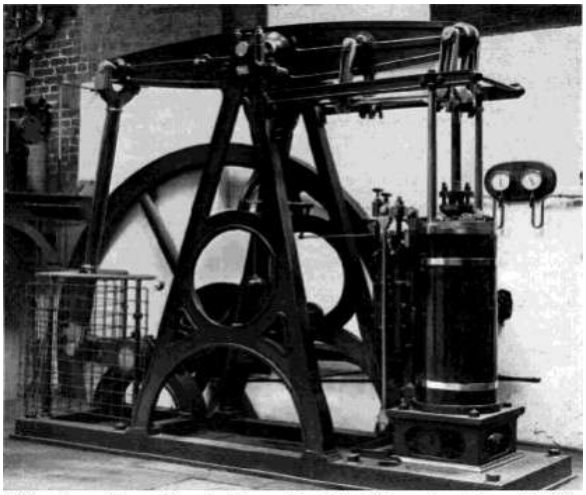
dangerous if it is not built with the appropriate materials, techniques, and designs. This applies to all fluids that can be compressed and expanded.

A very important step was selecting the inspectors for these standards. The most important thing about a standard or certification is that it is respected. That's why the National Board of Boiler and Pressure Vessel Inspectors was organized in 1919.

To this day, these inspectors are appointed through a careful selection process, drawing from a wide range of backgrounds (mechanical engineers, naval engineers, etc.). Significantly, experience in the boiler field is highly valued (both in the operation of pressure and capacity boilers, and in the length of time they have been in operation).

These inspectors act under their own responsibility once they have obtained their certification; that is, they are responsible for the certification they issue and must attend refresher courses periodically.

What must be clear is that all these codes and inspections aim to ensure that boilers and pressure vessels are safe to operate, not merely a bureaucratic formality to obtain an operating permit.



Máquina alternativa de fines de siglo 18 y principios del 19
Posiblemente construida por Boulton y Watt.

Boiler accidents still occur today.

The lack of training among people is perhaps the main cause of these accidents.

The irresponsibility of some individuals who give the false impression that

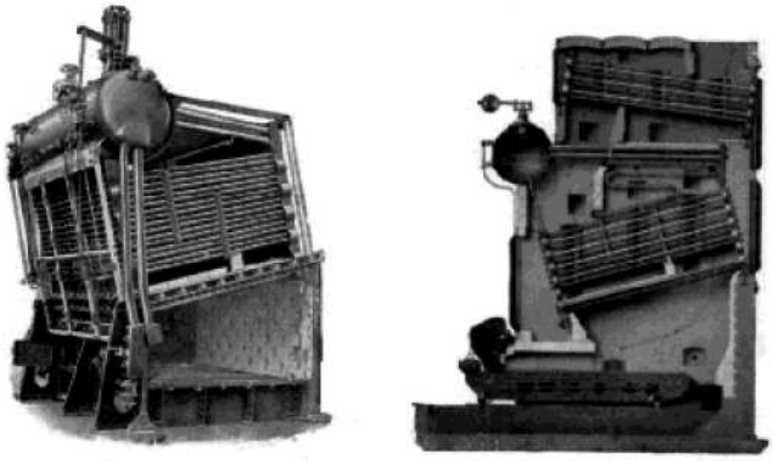
they know about the subject, some selling repairs, treatments, related equipment, or providing incorrect instruction, allows these accidents to happen when they shouldn't.

Laws and decrees in Uruguay are not very clear (there is technical confusion among those who drafted them).

Inspectors play a very important role, since generally
people think, "This boiler passed the inspection, nothing will happen to it," but if the inspector has overlooked a potential cause of a future accident, this can be very dangerous... furthermore, boilers are dynamic, and there are other possible malfunctions.

Inspectors must be very careful when giving suggestions or making demands, as a misinterpretation can lead to a situation worse than the one they were trying to correct. (It's important to remember that a boiler is a dynamic element in its operation, and only those with real experience in its construction and, especially, its operation, with many years of experience, truly understand the subject in depth. They must interpret the regulations, which are a guide but sometimes cannot solve the problem on their own.)

There may also be unscrupulous or ignorant manufacturers who sell boilers that were not built according to standards (not all standards are equally safe). This often happens with imported boilers (they come with the insulation already installed, making structural inspections difficult under those conditions; it's like a doctor examining a patient in an overcoat!).



Old water-tube boilers from the late 19th century

Therefore, when buying a new boiler, you must demand that all applicable standards are met. This includes all standards: those related to materials, construction, inspection, operation, and all safety features.

When buying a used boiler, you should find out all the historical information regarding its construction, operation, repairs, etc., and conduct an inspection with all necessary tests to ensure that the boiler is in safe operating condition.

However, no matter how good or well-built a boiler is, it must be used properly, respecting all its operating limits, because In short, any boiler can be a "bomb."

It's a mistake to think that the more pressure a boiler can withstand (the same applies to a water heater), the less risk there will be.

This is false, since what's important is the working pressure limit, as well as the heat transfer limit, etc. If these limits are exceeded, the stronger the vessel, the stronger the expansion (the expansive or explosive effect).

To this list of problems related to construction and operation, we must add an important chapter: water chemistry. In water chemistry, it is crucial to consider that it is directly linked to safety, boiler efficiency, and steam quality.

The chemicals used must be among those that do not affect human health: some products are carcinogenic, while others are not yet clearly known to be so (some of them synthetic and almost indestructible).

In a plant, the steam from these products can come into contact with humans directly or indirectly (through handling the products, the steam, etc.).

There are also "miracle" mechanical devices (generally "magnetic") that treat water.

Extreme caution must be exercised with these, as we cannot rely on something that could lead to a dangerous situation in the boiler (due to scale buildup). Significant accidents have occurred.

Stoker Boiler´s Handbook 2011, C.W.T. – INTRODUCTION

It's important to remember that the most crucial aspect of a boiler is the cooling of the metal surfaces subjected to heat transfer. These surfaces are exposed to the high temperature of combustion or its hot gases on one side, and to water or steam on the other, which cools the metal by absorbing heat.

However, a layer of scale or a surfactant phenomenon can interfere with this cooling process. These scales can burn or collapse, so ultimately, the internal circulation of water or steam in a boiler is the most important condition to consider.

FLOW LACKING COLLAPSED BOILER HEARTH

But we also have to take into account that an excessively clean boiler can be a boiler losing metal thickness (the metal in contact with the water is protected by a layer of magnetic oxide, so if this layer dissolves, the metal is attacked, losing thickness; hence, a boiler should preferably be scaled, within the limits of safety and efficiency, but its corrosion should never be allowed; corrosion cannot be fixed, controlled scaling is always cleanable).

This concept was already very clear to one of the "masters" of boilers:
The following is a copy of the book *Boilers* by Carl D. Shield, which summarizes the idea of a perfect boiler, originally presented in 1875 by Mr. Stephen Wilcox.

Note: Despite the years that have passed, this idea remains undeniably valid, but there are still those who do not apply it.

Stoker Boiler´s Handbook 2011, C.W.T. – INTRODUCTION

Mr. S. Wilcox stated in 1875:

1. Proper workmanship and simple construction, using materials that experience has shown to be the best, thus avoiding premature repairs.

2. A sludge collector to receive all the impurities deposited by the water, positioned so that it can be removed outside the action of the fire.

3. Sufficient water and steam capacity to prevent fluctuations in steam pressure and water level.

4. A sufficiently large surface area for the release of steam from the water to prevent foaming.

5. Constant and complete circulation of water within the boiler to maintain a uniform temperature throughout.

6. The water space should be divided into sections arranged so that if one of them fails, a general explosion cannot occur, but rather the destructive effects are confined to the escape of the boiler's contents.

7. Wide, unobstructed passages between Different sections, so that the water line and pressure are identical throughout the entire assembly.

8. Extremely high strength, exceeding any justifiable deformation; and a boiler construction that is free from deformations caused by uneven expansion and, as far as possible, avoids joints in parts exposed to fire.

9. A combustion chamber constructed so that the combustion of the gases, which begins in the firebox, is completed before these gases escape through the chimney. (Note: Currently, it is essential that combustion is completed virtually within the firebox.)

10. That the heating surfaces approximate a right angle to the direction of the hot gas flows, so that these flows are interrupted to extract the full heat content from the gases.

11. All parts must be easily accessible for cleaning and repairs. This is a condition of paramount importance because it relates to both safety and accessibility. Economy.

11. It must be proportionate to the work to be performed and suitable for operating at its maximum capacity with the highest economy.

12. It must be equipped with the most modern measuring instruments and safety valves, as well as other accessories.

Babcock & Wilcox Co. “Steam, Its Generation and Use”
https://ia600702.us.archive.org/4/items/steam-its-generation-use-stultz/SteamItsGenerationUseStultz.pdf

In Uruguay
The first boilers were probably those installed on ships used for long-distance and coastal shipping (both on the Río de la Plata and the Río Uruguay), in threshing machines, in some mills, and on railways.

In the case of the threshing machines, many accidents were costly due to the precarious working conditions (far from workshops, with unsuitable water, etc.).
The boilers used were of the mobile type with wheels for transport.

COAL-FIRED LOCOMOTIVE BOILER

It is a very common fire-tube boiler in Uruguay until the mid-20th century, with two tube passes and an external pass in the firebox ("hot belly"), extremely "dangerous" due to the settling of sludge on the firebox in the area of the casing, which hinders heat transfer and causes it to rupture in the fire. This type of boiler caused many accidents. They were adapted for F.Oíl.

The railways (currently AFE) were also initially powered by steam (burning wood and coal, later adapted to fuel oil).

The problem of water, which was loaded at various points throughout the country, necessitated periodic mechanical cleaning of the water chambers.

Many firemen and technicians for industry and workshops came from these railway workshops.

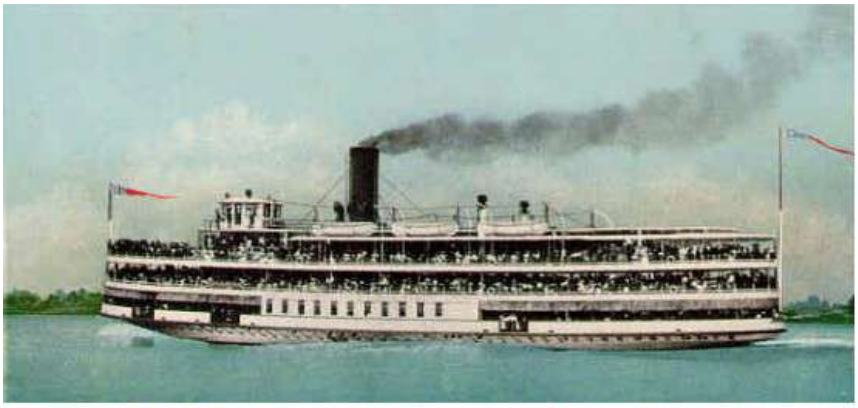
The port's winches were powered by reciprocating steam engines, fed by vertical boilers.

The state-owned electric power plant (UTE) has been and remains the main steam plant (high pressure), although in earlier times it operated smaller plants in inland cities.

The supply of drinking water to Montevideo (now OSE) was provided by boilers and reciprocating engines. The oil refinery (ANCAP) also uses energy from medium-pressure boilers with its own power generation and process gas utilization.

Some industries, such as large meatpacking plants, the textile industry, breweries, and the sugar industry, had large steam plants with turbines and their own power generation. These plants operated at medium pressure, using superheated steam.

The paper industry used medium-pressure boilers and process recovery boilers, with turbines and their own electricity generation. Some sand quarries and other extraction operations had boilers to power their machinery, now largely replaced by internal combustion engines.



Steamship from the late 19th and early 20th centuries

The ships, formerly called steamships, the very name indicating the importance of their boilers in propulsion and electricity generation. Today they have switched to diesel engines. One of the best known in recent times, the Tacoma, had low-pressure (fire-tube) boilers with steam turbines. The tankers of ANCAP (the state-owned oil company) and the Navy also used diesel engines.

The port tugboats. The "route steamships" from the last century (which connected Salto, Montevideo, and Buenos Aires) were the most famous. Many lives were lost in accidents caused by boiler failures (problems typical of that era).

The laws and decrees in Uruguay, although there may be earlier ordinances, stem from Law No. 5032 of July 21, 1914, concerning Workplace Accidents. This law was implemented over time, specifically for boilers, beginning with the law of February 7, 1925, which granted technical oversight of boilers to the Mining and Industries Inspection (later the Directorate of Industry).

Even then, annual visual and operational inspections were promoted, with more comprehensive inspections, including hydraulic testing, to be carried out every four years.

Later, by decree of December 3, 1925, three categories of boilers were established: Low pressure (up to 2 kg/cm²), Medium pressure (over 2 kg/cm² up to 4 kg/cm²), and High pressure (over 4 kg/cm²).

Today this classification has no technical meaning since the pressure limits are arbitrary, that is, everything is very relative, so today the heating surface is used which gives a clearer idea about the size of the generator.

By law of January 31, 1935, the control and collection of taxes was transferred to the Directorate of Industries.

The decrees of March 11, 1927, June 1930, May 15, 1933, November 1934, and August 31, 1938, established the framework for the General Regulations. These regulations governed all operations related to the control, transfer, and sale of steam generators.

A decree of July 24, 1933, regulated the use of welding in boiler repairs (it should be noted that boilers were generally riveted). This decree provided some very general technical standards regarding responsibilities and procedures. It stipulated that workshops performing significant repairs (such as pressure vessels) required a responsible specialized engineer.

The decree of November 29, 1940, regulated the procedures and responsibilities of boiler owners and repair shops. The owner or the shop that carried out the repair was always primarily responsible, not the inspector who certified the boiler.

The Directorate of Industries would be the supervisor, although the National Institute of Labor and Related Services would be responsible for applying sanctions.

In summary, regarding boilers, even back then:
Inspectors were required to verify the accuracy of the pressure gauge readings, using a standard gauge. Safety valves were to be sealed once calibrated (the Directorate of Industry would be responsible for verifying these seals).

The most important procedures for handling hazardous situations and the procedures to be followed during inspections were outlined.

A logbook was kept of inspections and repairs (Decree of March 11, 1927), but all breakdowns or repairs had to be reported to the Directorate of Industries (Decree of November 29, 1940).

As for the boiler operators, they were required to have a certificate of competence from the Directorate of Industries (Decree of August 3, 1945).

Decree 406/988 (Ministry of Public Health), in Chapter IV, regulates a number of elements or processes related to boilers and pressure vessels, their maintenance, and operation.
By Decree of March 12, 1997, it was agreed that the Ministry of Industry,

Energy and Mining (MIEM) could transfer the technical inspection of steam generators to the Technological Laboratory of Uruguay (L.A.T.U.).

Today, legislation is evolving, given the significant changes in steam generators (Decree 190/997 being the one that transfers the requirement for obtaining a boiler operator's license to the Technological Baccalaureate in Thermodynamics (Heating and Cooling) at the Diving Technical School). Further changes are likely in this period (2011) for various reasons.

As of January 1, 2011, in accordance with Law 18.719, the authority to regulate and oversee the operation and safety conditions of steam generators was transferred from the National Directorate of Energy and Nuclear Technology (DNETN) of the Ministry of Industry, Energy and Mining (MIEM) to the Regulatory Unit for Energy and Water Services (URSEA).

However, some valuable aspects of these previous laws and decrees, some of which are no longer in use, remain. For example, one requirement was for each generator to centralize all information throughout its useful life in a logbook on-site (this serves as a record, which is very important).

Another requirement was the on-site inspection of pressure gauges, since even a calibrated and sealed pressure gauge can malfunction between the calibration and sealing location and its installation on the boiler.

I disagree with the regulation regarding the daily purging of the pressure gauge connection (this causes corrosion and fatigue in the gauge). Perhaps the reason for this requirement was the fear that the gauge was seized (a very likely scenario in those times when water treatment was practically nonexistent).

I believe that dynamic pressure testing of the opening and closing (using the boiler's own pressure) of the safety valves is a good thing; it's the only way to ensure they operate correctly, and they should be sealed by the inspector.

However, capacity tests should also be performed (something I've never seen done in 45 years), especially on new boilers. The pressure gauge should also be checked using a standard gauge (under the inspector's responsibility).

Since a supposedly "certified" pressure gauge can be damaged during transport between certification and its place of use (a situation easily controlled with calibration using a standard pressure gauge, specifically designed for this purpose and subject to frequent checks, as pressure gauge valves have a plate for connecting the standard gauge without needing to

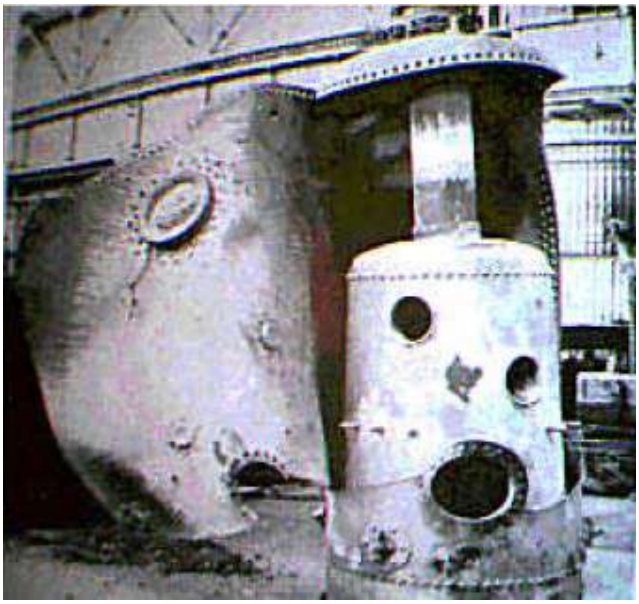
disconnect the installed gauge; see the corresponding chapter). This was already regulated.

It is good safety practice to test boiler casings not only against failures but also due to the effects of time: such as the 25-year test, in which all insulation must be removed and a thorough inspection of the pressure vessel must be carried out (thickness, weld inspection using non-destructive testing methods, etc.).

But what remains crucial is the observation of the entire boiler casing and the checks carried out in the logical locations where corrosion, fatigue, or wear problems might occur (these points are generally in hard-to-reach areas).

Hence the importance of the inspector's or company advisor's expertise, since simple measurements and tests are often insufficient to truly assess the "questionable" safety condition of the boiler.

We have decommissioned boilers that were declared "in good condition" by companies specializing in casing measurement and inspection (since visual inspection reveals things that only "experience" shows). Because there is no more serious accident than a casing that cannot withstand the pressure and ruptures in an explosion!



OLD VERTICAL BOILER.
This boiler has suffered a casing explosion, the most dangerous type of accident, generally caused by structural failures, caustic attack on the rivets, or simply excessive pressure.

In this past year (2011), legislation continues to evolve, but some questions remain:

Stoker Boiler´s Handbook 2011, C.W.T. – INTRODUCTION

What are boilers today?

a- A pressure vessel (as was the case until the mid-20th century)

b- A set of mechanical, electrical, electronic, and chemical engineering components (a product of the need for automation and the high efficiencies that are sought, with very high vaporization rates per square meter of surface area).

In my opinion, boilers are no longer simply a "pressure vessel" (as they were more than 50 years ago). Back then, boilers not only had construction problems (materials and procedures, tools like welding, etc.), and their low vaporization rates per square meter and lack of automation were problematic; the pressure vessel itself was the main issue.

Today, high automation and high specific vaporization make the pressure vessel as important as the automation (electrical and electronic), or perhaps the internal circulation (which is the most important, depending on the design and chemical treatment), or the chemical treatment, which influences both heat transfer and internal circulation (since high vaporization does not tolerate scaling, corrosion, carryover, etc., or the simple physicochemical alteration of the water under the conditions it is subjected to inside the boiler).

So the big question is: who are the professionals exclusively trained in "boiler knowledge"?

In answering this question, I believe there isn't a specific profession, but rather a "suitability" with a university or technical foundation (whether they are mechanical, industrial, naval, electrical, electronic, or chemical engineers, or technologists from related fields).

And evidently, in each section, there will be some whose backgrounds facilitate their understanding, and therefore, on specific and high-risk topics, they will have the floor. However, they must not forget that there is no limit to the scope of each topic, preventing it from being isolated from the others.

For an excellent boiler as a pressure vessel is useless if its internal circulation is poorly designed, or if the (automatic) safety elements are inadequate or not properly adjusted, or if the chemical treatment is simply not appropriate for the circumstances.

Now you are the protagonist; let's delve into the topic on the following pages...

Definitions of a steam boiler:

Steam boiler: A vessel where water boils, the steam from which is used as the motive force of a machine. -- Sopena Universal Encyclopedia. --
A steam boiler is a closed vessel designed to produce steam at pressures above atmospheric pressure, using the heat generated by burning a solid, liquid, or gaseous fuel. -- "Marine Boilers" by Moisés Romero Villanueva. --

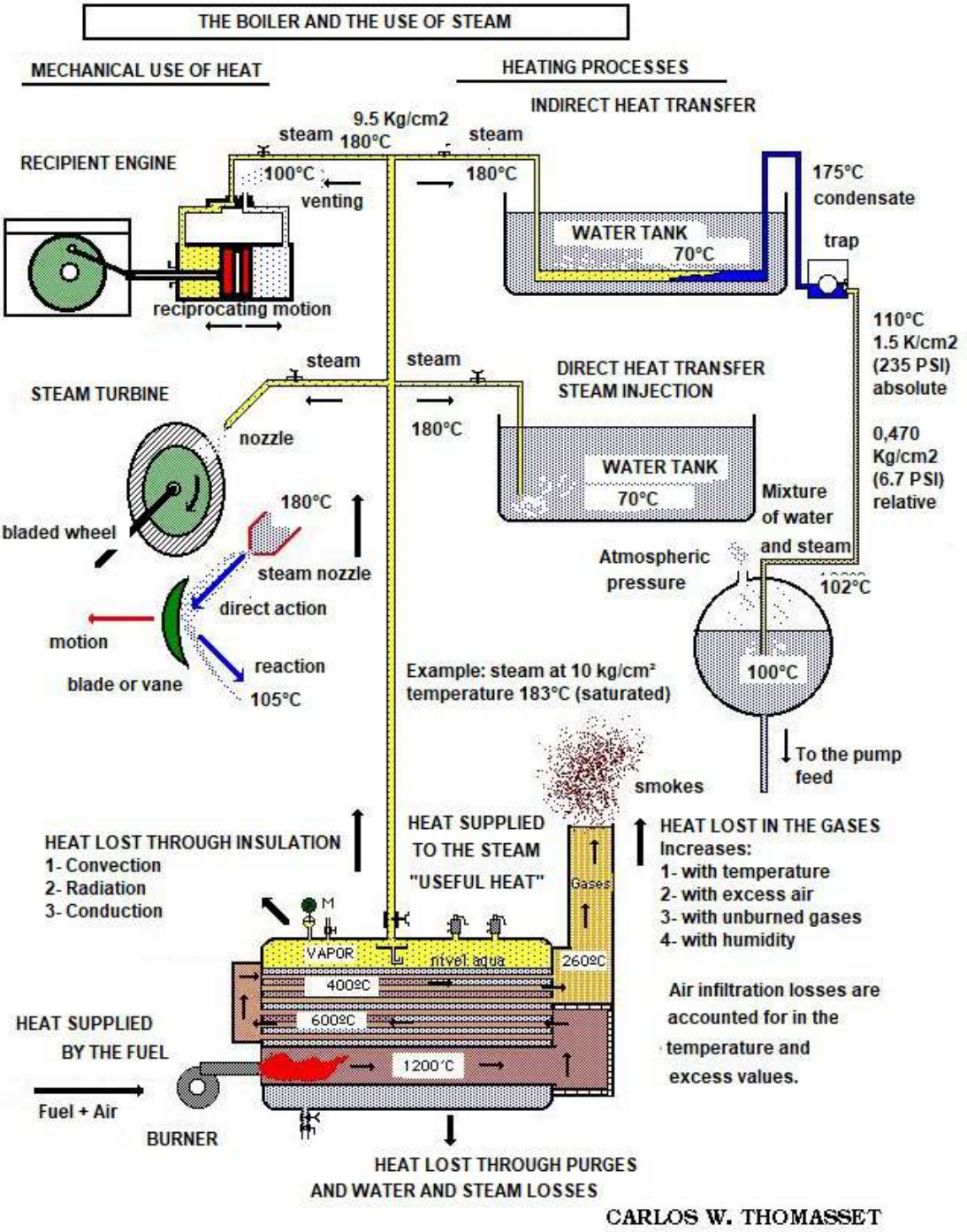
A boiler is defined as: a closed vessel in which water is heated, steam is generated, steam is superheated, or a combination of both, under pressure or vacuum with the direct application of heat.

The term boiler may also include combustion units for heating or vaporizing liquids other than water; these are closed systems within themselves. -- The American Society of Mechanical Engineers. --

In this short manual, we will refer to a steam boiler and define it as follows:
A closed vessel for the production of steam:
for the transfer of heat or its transformation into motive power, heated directly by the combustion of a liquid, gaseous, or solid element in contact with air.
Equipped with devices for the control and safety of its operation.

For the purposes of this short manual, we exclude: electrically heated boilers, thermal fluid boilers, heat recovery boilers, furnaces, etc., although there may be elements discussed here that are associated with them.

The previous definition tells us that a boiler is a device that transforms the "chemical heat" that is latent in a fuel and that, when "burned" in the air (combustion), releases heat that is transported through the metal wall of a container holding water. This water, upon absorbing the heat, increases its temperature (sensible heat) until it evaporates (latent heat), and this heat is then transported in the steam until it is used as heat (process heating) or work (reciprocating steam engine, steam turbines, etc.).



As we can see, a number of elements come into play for the operation of a boiler.

To understand and operate a boiler correctly and efficiently, it is necessary to know these elements and how they work.

1- The Basic Boiler
2- Water and Steam
3- Fuels
4- Boiler Components
5- Operation
6- Emergencies
7- Maintenance
8- Steam Installation
9- Boiler Efficiency
10- Electrical Controls
11- Structural Failures
12- Safety Valves
13- Packings and Gaskets
14- Drying Firewood
15- The Superheater
16- Heat Recovery Units
17- Preparing Boiler Water
18- Boiler Water Monitoring
19- Boiler Blowdown
20- Chemical Cleaning
21- Tube Boring
22- Tube Extraction
23- Refractories
24- Considerations When Purchasing a Boiler
25- Burner Information
26- Energy Saving Tips
27- Useful Tables and Data

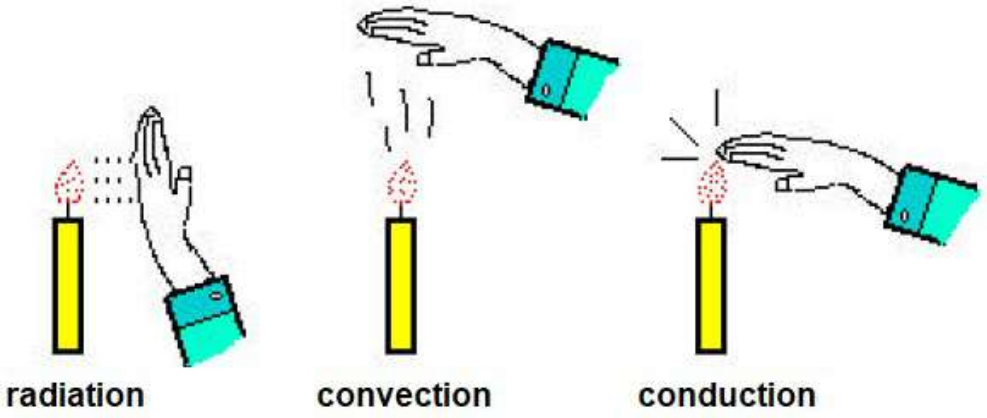
CHAPTER 1: The Basic Boiler

We will define the basic boiler to be able to delve into the different topics with a basic understanding of the boiler itself.

As we have seen in the previous definitions, a boiler is a closed container made of iron and tubes (of special steel for boilers) that is composed of sections where water circulates and sections where hot gases circulate, transferring heat to the water.

According to the laws of physics, this heat is transferred through the metal walls from the hotter gases to the cooler water or steam.

Heat is transferred in three different ways: radiation, convection, and conduction.



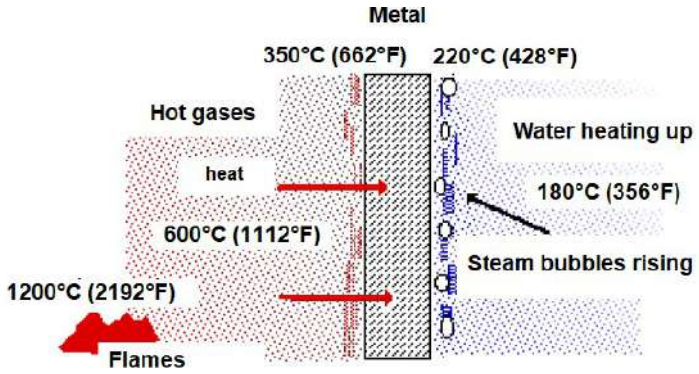
None of the methods of heat transfer exist in isolation in practical life; they are always combined.

Example: While the heat supplied by an electric "radiant" heater (quartz heaters, "rollers," etc.) is predominantly radiant, its heating elements and the surrounding objects are heated by radiation, and these, in turn, heat the surrounding air by conduction.

As the air heats up, it carries the heat to the environment by convection (it circulates as its density decreases), further heating other objects, and so on.

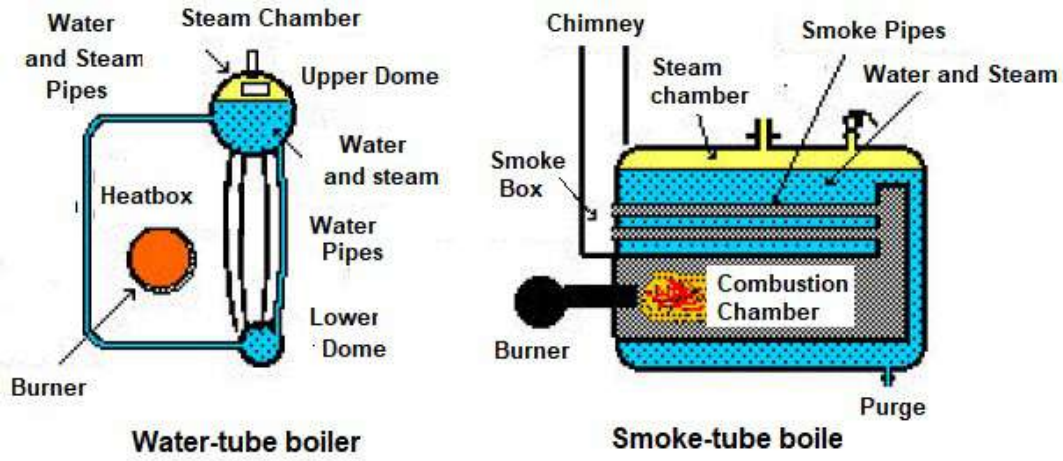
Later we will examine the challenges of transferring this heat through metal between a gas and water (or steam).

Based on the relative position of the gas and water circulation, we find the first major division in boiler construction: water-tube boilers (where water circulates inside the tubes) and fire-tube boilers (where gas circulates inside the tubes).



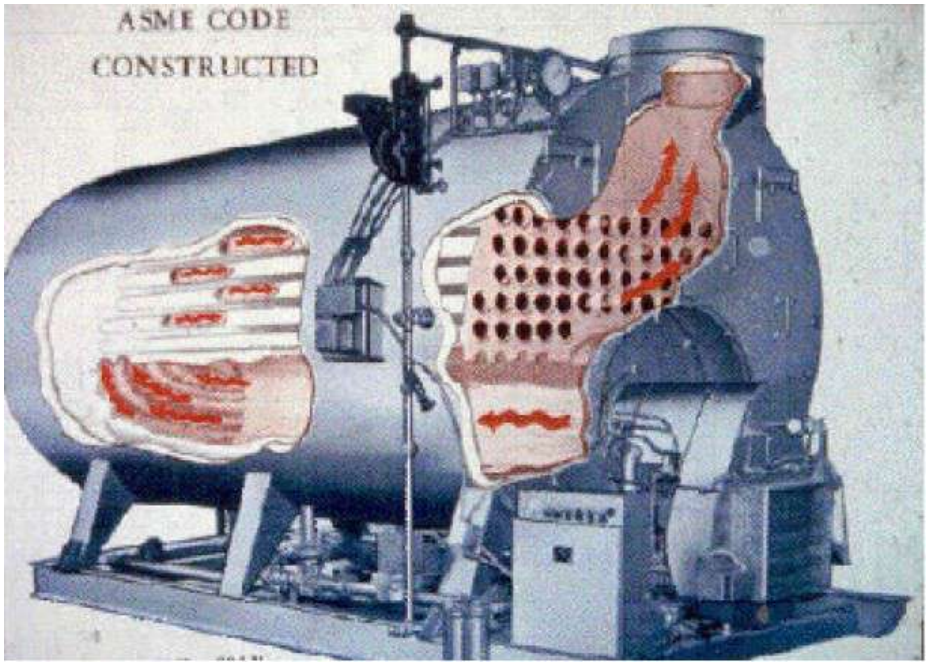
The water-tube boiler consists of vessels (domes and headers) connected by tubes through which water and steam circulate. These surround a combustion chamber, whose heat is transferred to the tubes from the outside.

These boilers were called "explosive-proof" due to their resistance to explosions or accidents. (This is not entirely true under incorrect operating conditions, as they can be prone to combustion chamber explosions.)



The fire-tube boiler (also known as smoke-tube boiler) consists of a vessel through which a cylindrical firebox (usually, although in some cases it may be dome-shaped) and tubes circulate, carrying the combustion gases.

These are the most common type of boiler found in the market, and their working pressure is limited by the size of their body (which subjects the material to high stress).



The most basic boiler we can imagine is the "pressure cooker," used for cooking, but which doesn't fulfill the function of a boiler: producing steam for external use (although its function is similar to a "digester": producing cooking temperatures higher than 100°C (212°F), being the boiling point of water in a regular pot at atmospheric pressure). Because it's subjected to direct heat, we can consider it a very basic boiler to which we must add the missing elements to make it a steam boiler.

In a pressure cooker, we have a certain level of water and a steam chamber (the space that the water vapor occupies when pressure is increased and some of the water evaporates).

This cooker has a maximum working pressure valve, which allows the steam pressure (and therefore the internal temperature) to be raised to a necessary level (which we can consider a pressure regulating and safety valve).

As a maximum pressure safety mechanism, it has a plug that pops open at a higher steam pressure (which we can consider a maximum safety valve or seal).

In a pressure cooker, when the pressure reaches a point where the regulating valve opens, the heat is reduced to decrease steam loss to the atmosphere and prevent the cooker from running out of water.

The goal of a pressure cooker is to achieve a temperature above 100ºC, meaning that the steam pressure is greater than atmospheric pressure.

There are significant differences between this pressure cooker and a boiler. Let's examine them:

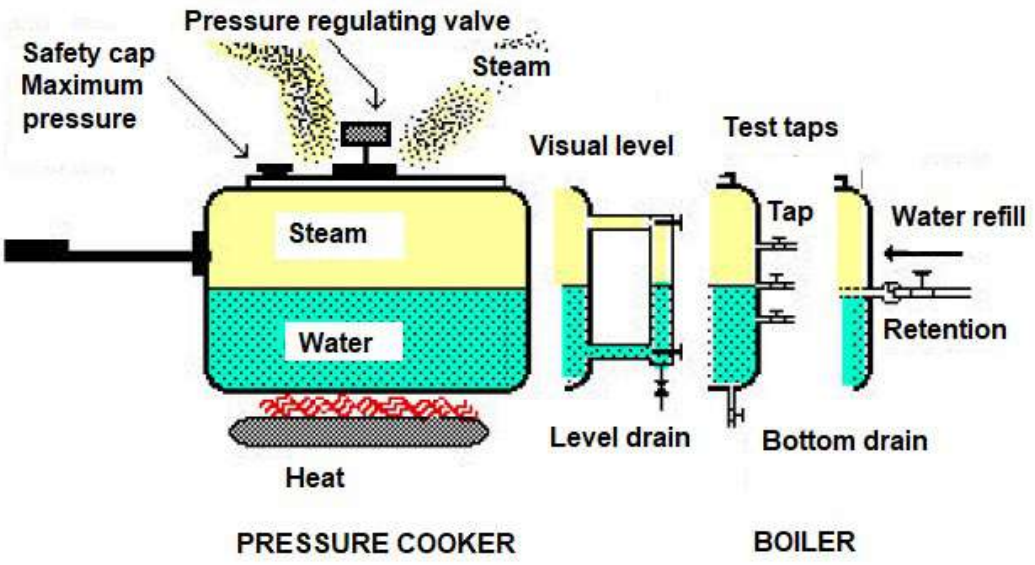
1- Its function is not to produce steam for consumption, as the amount of water is insufficient. If we were to use the steam, we would need to connect a pipe with a higher water pressure than the pressure inside the cooker, a valve to regulate the amount of water entering, and a level indicator to monitor the water level.

We all know that if the water runs out, the metal will "burn" due to contact with the fire (high temperatures), which is the most common cause of accidents involving boilers.

The sight glass (made of special glass) must have a protective mechanism in case it breaks and shatters, and connection valves (for when it breaks), good lighting, and a purge valve to remove any debris that might clog it (this debris is sludge formed by the precipitation of salts carried by the water).

Since the connections to the steam chamber and the water chamber of this tube can become blocked (or the tube can break while the boiler is running, or the boiler can lose its sight glass: for example, a high level where there is only water in the tube or a low level where there is only steam; in both cases, it is not possible to tell which situation is occurring at first glance.

Sometimes purging the level can reveal it, but it is not easy), therefore, there must be a system to easily check if the water level is within a certain range (covering the metal surface heated by the fires).



Three level test valves are installed. The top valve releases only steam, the bottom valve only water (and "flash" steam – water that evaporates due to lower pressure), and the middle valve releases steam depending on whether the water level is above or below it.

2- The steam pressure to be produced will not be controlled by releasing steam into the atmosphere, but by controlling the amount of fire.

For this, the combustion system (regardless of the fuel) must have a combustion quantity regulation system.

Normally, for liquid and gaseous fuels, we will regulate the amount of fuel and air entering the combustion chamber, either manually or automatically.

For solid fuels (firewood, coal, etc.), we will regulate the air (without air there is no combustion) manually or automatically (since the firewood or coal is in a significant quantity in the firebox, which

we cannot remove, although we can later decrease or increase its hourly rate).

3- We will see that the maximum amount of steam produced depends on the maximum amount of combustion, but this is limited by the surface area of the metal that transmits the heat.

If we want more steam, we must increase the "heating surface" (the metal surface exposed on one side to the heat of combustion and on the other side to contact with the water—or a mixture of water and steam).

To achieve this and to make better use of the heat, it became necessary to pass the "flues" (hot combustion gases) through the tubes, creating the "fire-tube" boiler.

Later, due to the need to work at higher pressures and with greater safety, the "water-tube" boiler was created. If we consider boilers from the perspective of their operating pressure, we can establish three arbitrary categories: low-pressure boilers, medium-pressure boilers, and high-pressure boilers.

This division is also standardized by various associations (standards), but we will divide it arbitrarily according to our understanding, based primarily on the pressure related to the quality of the water used (we will see later the importance of the water used with respect to operating pressure and boiler type), and we will specify which types of boilers fall within these pressure ranges:

- **Low-pressure boilers**: Up to 10 kg/cm² (142 PSI), fire-tube boilers predominate.

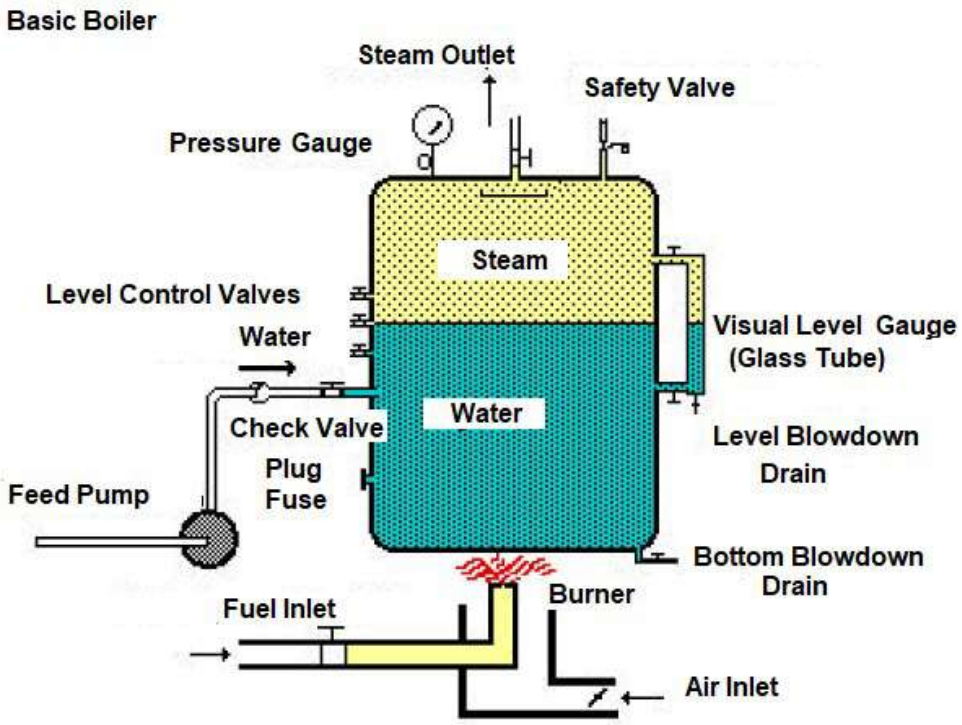
-**Medium-pressure boilers**: Up to 30 kg/cm² (427 PSI); above 20 kg/cm² (284 PSI), water-tube boilers predominate.

-**High-pressure boilers**: Above 30 kg/cm² (427 PSI), only water-tube boilers are available.

4- To function as a steam boiler, our basic boiler (the pressure cooker) must be fitted with a pressure gauge to measure the steam pressure (generally, the pressure should be kept constant).

This gauge will allow us to control the amount of combustion needed (without a pressure gauge, it's impossible to control a boiler; we'll see that each pressure corresponds to only one temperature when water and pure steam are in a closed container).

A steam outlet valve (to open and close the supply of steam for consumption), and a bottom blowdown valve (for removing sludge and dissolved salts that accumulate in the boiler water, resulting from the salts present in the incoming water and the chemicals used in its treatment).



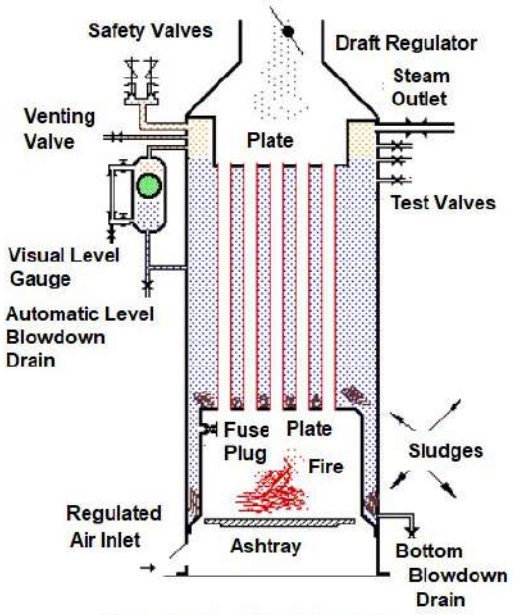
This boiler is missing other necessary, but not essential, elements, which we will see in the following topics.

To introduce this same water, we will need a water pump with sufficient pressure to overcome the boiler's internal pressure. (This pump must be connected to the boiler with a check valve, which allows water to enter the boiler when the supply is turned on, but prevents the boiler pressure from overcoming the pump pressure at any point if the pump pressure drops, or if the pump stops and water escapes from the boiler.)

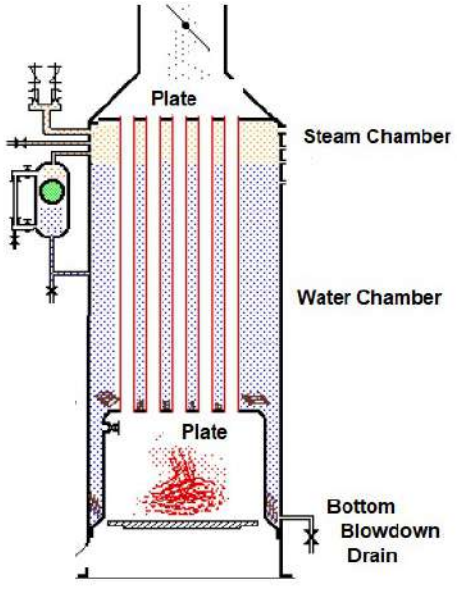
The pressure regulating valve will be called a safety valve (its function will be to release excess pressure if we cannot reduce the combustion rate in time).

There must be a "fusible plug" (so that it "melts" due to the heat and releases pressure if the boiler runs out of water or the water level drops below a certain limit, supposedly "capable of extinguishing the fire" with its steam release, or at least providing a warning that the low water level is occurring in order to stop combustion).

In the past, the plug was also used as a temperature limiter due to pressure rise, but the melting point became very uncertain, since the melting materials (tin and others, combined) changed their composition under operating conditions (temperature changes, exposure to the environment, etc.), altering their melting point.



Vertical Boiler with Wet Top Plate



Vertical Boiler with Dry Top Plate

Currently, the aim is to use pure materials that do not decompose, such as pure tin, whose sole function is to control the presence of water ("melting" due to the heat in case of water shortage).

For startup, when the boiler is cold, we must have an "atmospheric valve" to release the air from inside the boiler as it heats up (or to break the vacuum when emptying it). There will be a series of accessories, some necessary (but not essential) and others essential, such as those mentioned above.

Our "pressure cooker" will be transformed into a steam boiler by incorporating all these minimum necessary elements: Pressure gauge. Visual level control. Safety valves. Direct level control (valves). Fuse plug. Level and bottom drains. Feed pump and its control and check valves. Steam outlet valve.

Fuel and air controls, and other necessary or essential accessories according to the desired boiler design.

It is important to clarify that pressure not only controls the steam temperature but also defines the limit for controlling the stress the vessel must withstand (maximum working pressure limit).

This means that if we exceed the working pressure limit, we are running the risk that the pressure vessel or boiler may rupture and its expansion into atmospheric pressure will not only cause structural damage, but also thermal damage ("burns") and secondary effects, such as a second over-pressure on the walls of the enclosure and in turn the "bursting" of said enclosure (walls, ceilings, etc.).

SUMMARY:

This basic boiler operates by harnessing the heat produced by combustion. The amount of heat can be regulated according to need (maintaining working pressure) by adjusting the amount of fuel and air.

This heat is transferred to the water (a mixture of water and steam) through the metal, causing the water to vaporize, first by raising its temperature (sensible heat) and then by evaporating it (latent heat).

This steam is then forced by the generated pressure into the pipes where it will be consumed (condensed).

The amount of water entering through the feed must equal the amount of water that evaporates plus the amount that must be extracted through blowdown and other losses.

We have sufficient protections to maintain the pressure within a maximum limit and to maintain the appropriate water level. The fusible plug serves as a protection in case the water level drops too low and we are unable to extinguish the fire.

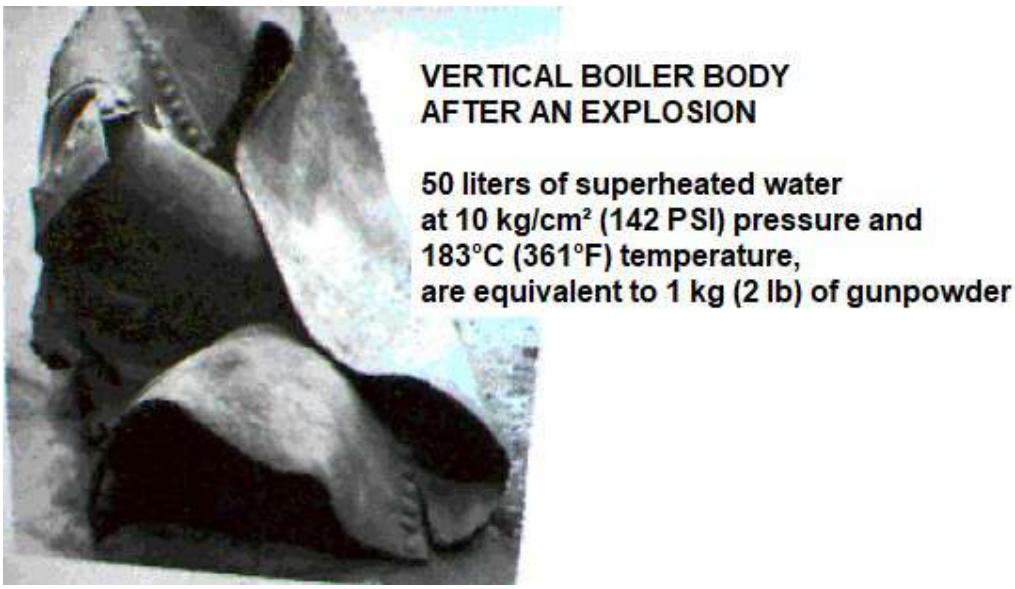
CHAPTER 2: Steam and Water part 1

Part 1 - Steam:

Water, in the form of steam, is the element responsible for transporting the heat generated during combustion (rapid oxidation of the fuel) to the point or location where this heat will be used for a thermal or mechanical process. There, it will revert to water (condensate), which may or may not be recovered.

This means that water only acts as a "heat or energy conveyor belt."

However, while it is an easily obtainable medium with many advantages, it also has its problems. Therefore, we must understand its mechanics and the issues involved in its use. In its application, we will use pressure and temperature as constant parameters to define its condition, and we will also refer to the unit of heat.


VERTICAL BOILER BODY
AFTER AN EXPLOSION
50 liters of superheated water
at 10 kg/cm² (142 PSI) pressure and
183°C (361°F) temperature,
are equivalent to 1 kg (2 lb) of gunpowder

Let's clarify these terms: Pressure: We can define it as the expression that indicates the units of force applied per unit area.

Depending on the units used to measure force and the units of area, we can talk about kilograms per square centimeter (kg/cm²), pounds per square inch (PSI): lb/in² or lb/in², etc.

It can also refer to a comparison with other pressures: such as atmospheric pressure, the pressure exerted by a certain height (expressed in m, cm, mm, or inches) of water or another liquid (for example, mercury), etc.

All these units can be expressed in an equivalent form if we use a conversion factor.

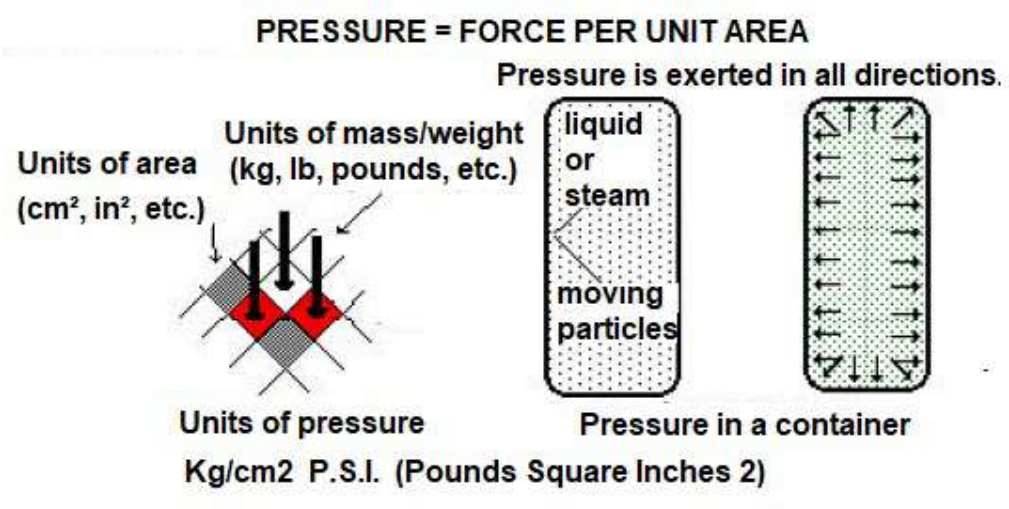
For example:

1 kg/cm² multiplied by 14.22 gives us the pressure in PSI (lb/in²).

1 kg/cm² multiplying this by 10 gives us the pressure in meters of water column.

The pressure indicated by pressure gauges is generally the "gauge" pressure.

The "absolute" pressure is the sum of the atmospheric pressure and the gauge pressure.



But what is pressure in liquids and gases (vapors)?

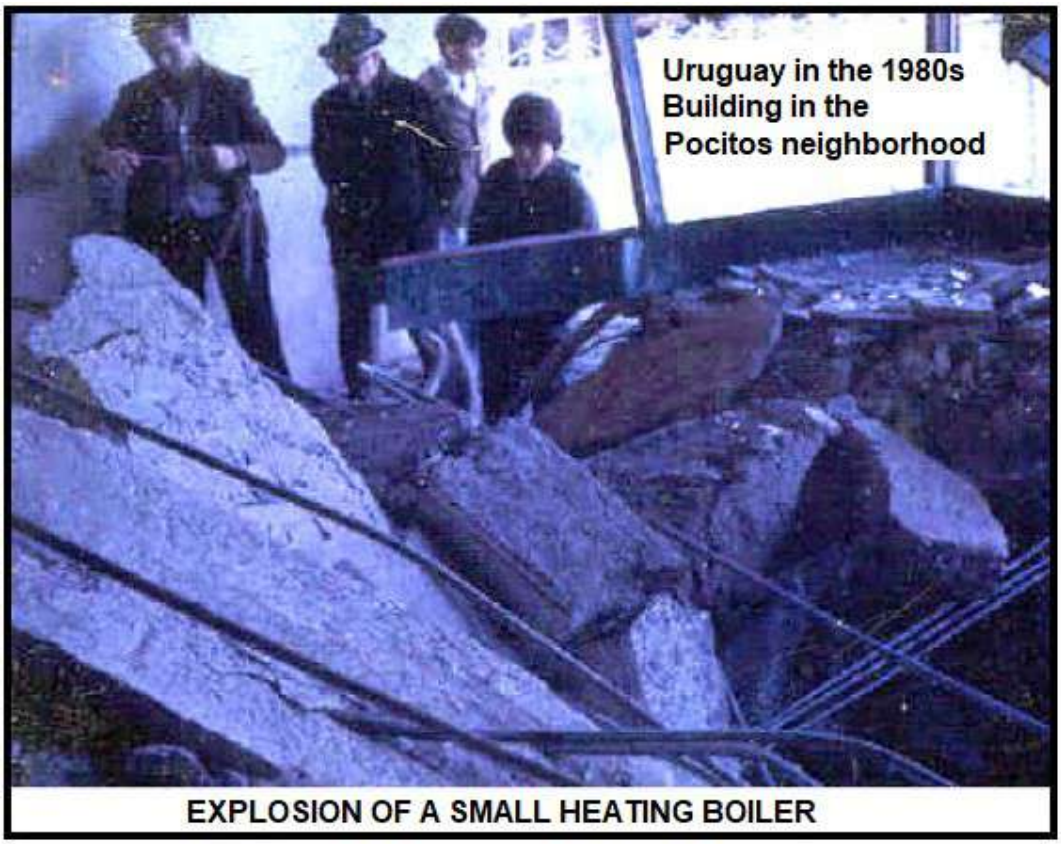
It is the force exerted by molecules on the walls that confine (contain or support) them. A molecule is the smallest part of a pure chemical substance that can be identified as such—if we break a molecule, it will cease to be that substance and transform into another.

If we disregard the weight of liquids and gases (vapors) and consider the weight of the molecules as projectiles, we see that these particles exert pressure in the form of "impacts" on the walls (of the containers).

We can increase these "impacts" by "reducing the size of the container" (or increasing the amount of substance inside) or by increasing the speed of the molecules (number of impacts) by increasing their temperature (their energy level).

In other words, we can increase pressure by "pumping" (with a pump) the fluid or by increasing the energy of the fluid (by supplying it with heat, as in boilers).

Since these "impacts" occur continuously and "hit" the walls of the container, this causes the pressure to be exerted equally in all directions (this is not so much the case when we consider the pressure exerted by simple weight - the "lower" a wall of the container is located, the greater the pressure it must withstand due to the "pure" weight of the substance: the force of gravity).



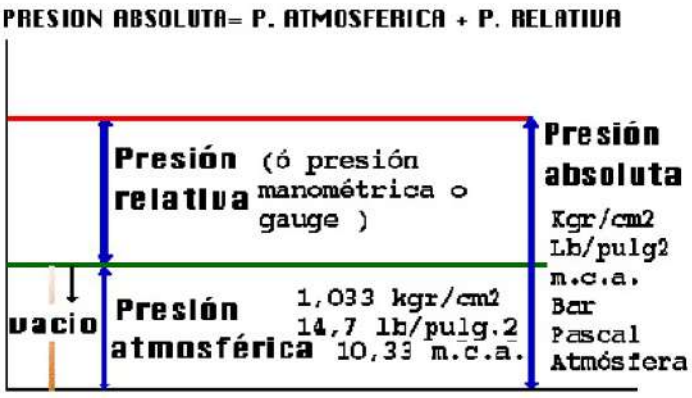
EXPLOSION OF A SMALL HEATING BOILER

We will see that a "pressurized" container does not necessarily "explode" with compressed gases inside. Rather, these gases can form and expand from "superheated" liquids (such as hot water with temperatures above 100°C or other gases at lower temperatures, such as those used in refrigeration (ammonia, freon, etc.) or even for extinguishing fires, like CO2).

These "superheated" liquids, upon contact with lower pressures, vaporize and "expand," creating a volume many times greater than the one they occupy, as is the case in the previous photograph. In a relatively "small" heating boiler, for some reason the water temperature rose well above 100°C, causing high pressure in the container that made it "explode." The expansion of the vapor against the walls (with their large surface area) exerted its pressure and, consequently, a great force (due to the large surface area), resulting in what the image shows. (the explosion of a bomb).

In boilers, we will use pressure gauges to measure the pressure. We must carefully check the pressure units marked or engraved on the gauge (the units in which the pressure is indicated) and whether these correspond to absolute or relative readings.

Absolute pressure is the pressure indicated by a pressure gauge that displays atmospheric pressure (approximately 1 when its units are expressed in atmospheres, 1.033 kg/cm², or 14.7 PSI when it displays pounds per square inch) when its connection is exposed to the atmosphere (meaning that to read zero pressure, a complete vacuum must be created at its connection or port).



Gauge pressure, also known as relative pressure, is the pressure indicated by a pressure gauge that reads zero when its connection is exposed to the atmosphere.

Absolute pressure is equal to the sum of gauge pressure and atmospheric pressure (expressed in the same units: 1.033 kg/cm², 1 atmosphere, or 14.7 PSI, etc.).

We must be very careful when we say "pressure" to clarify which of the two we are referring to. (Generally, the pressure on pressure gauges is relative, which is why relative pressure is called "gauge" or "manometric pressure" in English).

Absolute or Vacuum Pressure Gauge scale in PSI bar (1 bar = 1.02 Kg/cm2)

Relative manometer scale in PSI and Kg/cm2

Boiler pressure gauges are suitable for this use (accuracy and temperature), and it is important to check them periodically (it may vary due to wear or fatigue), since the working effort that the boiler endures will be indicated by this pressure.

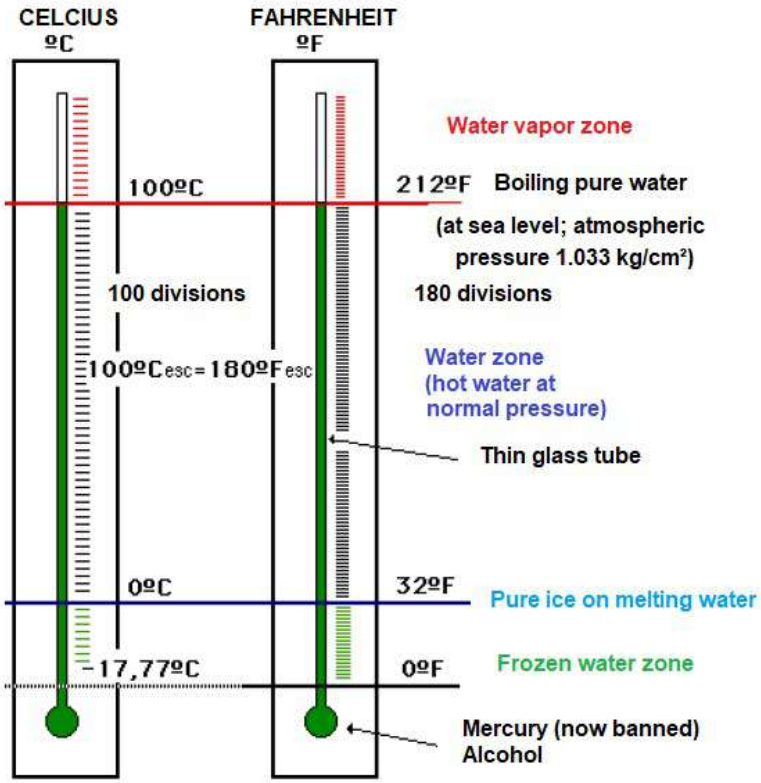
The pressure of water and steam in a boiler, when dealing with saturated steam and boiling water, accumulates thermal energy. If

this energy is released as mechanical energy (expansion) when the vessel containing and confining it (the boiler) ruptures (due to excessive pressure, poor construction, thermal or mechanical aging, corrosion, overheating, etc.), the vessel breaks and the resulting shock wave exerts pressure on the surrounding walls or any objects in its path, with catastrophic consequnces. See the previous figure of a vertical boiler, which, after rupturing or exploding, was projected hundreds of meters from its installation location.

TEMPERATURE

Temperature can be defined as the indication of the degree (energy level) of heat in bodies. Its numerical value depends on the temperature scale to which it is referenced and the starting point of the measurement (its zero point). We will generally work with two systems of units: degrees Celsius (°C) or degrees Fahrenheit (°F).

Temperature is measured with thermometers (temperature-sensitive devices), which indicate the scale to which they refer (°C or °F).



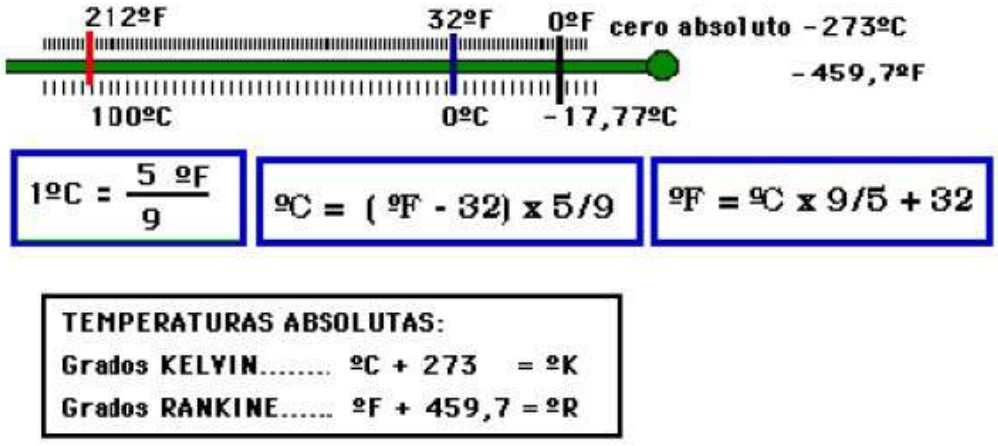
The thermometers in the figure are assumed to be exposed to standard atmospheric pressure (at sea level, whose atmospheric pressure is 1.033 Kg/cm2), for the measurement conditions over water, its vapor or frozen water (ice).

To establish both scales, we use the property of pure water that always thaws at the same temperature (at atmospheric pressure at sea level), establishing this as 0°C or 32°F, and that boils at the same temperature in an open container (at atmospheric pressure at sea level), 100°C or 212°F.

If we divide this scale (the expansion of mercury, alcohol, a metallic element, etc.) into 100 parts, we get 1 degree Celsius (1°C), and if we divide it into 180 parts, we get one part equivalent to 1 degree Fahrenheit (1°F).

We can convert from one scale to the other using the following:

(°C x 9/5 + 32) = °F (°F - 32) x 5/9 = °C



HEAT

Unit of Heat: We will define the unit of heat as the amount of heat required to raise the temperature of one unit of pure water by one degree within a given range (15°C or 17.5°C for the calorie).

According to the units, we have:

1 Kilocalorie = raising the temperature of 1 kg of pure water by 1°C.

1 BTU = raising the temperature of 1 pound of pure water by 1°F.

We can establish the relationship between the two by relating their base units:

Kilocalorie x 3.968 = BTU x 0.252 = Kilocalorie

As we can see, we are talking about the two most common systems of units in our region: the "metric" system (Kilocalorie) and the "English" or "imperial" system (BTU).

KCAL
1 KILOCALORIE = HEAT REQUIRED TO RAISE THE TEMPERATURE OF 1 KG OF WATER BY 1°C

BRITISH THERMAL UNIT (BTU) = HEAT REQUIRED TO RAISE THE TEMPERATURE OF 1 LB OF WATER BY 1°F

1 BTU = 0.252 KCAL 1 KCAL = 3.968 BTU

SATURATED STEAM IS STEAM THAT HAS THE SAME TEMPERATURE AS THE CONDENSING WATER IN CONTACT WITH IT

SENSIBLE HEAT
100 KCAL ARE NEEDED TO HEAT 1 KG OF WATER FROM 0°C TO 100°C

LATENT HEAT
539.4 KCAL ARE NEEDED TO EVAPORATE 1 KG OF WATER AT 100°C AT ATMOSPHERIC PRESSURE

1 KG OF WATER VAPOR AT ATMOSPHERIC PRESSURE OCCUPY 1.725 m³ (cubic meters)

1 kg of water vapor at 10 kg/cm² (142 psi) pressure occupies 0.18 m³ (cubic meters)

80 kcal are needed to melt 1 kg of ice

THE WATER

Let's talk about water and its physical and chemical properties.

Water (H_2O) is composed of two elements: oxygen (O) and hydrogen (H), specifically two hydrogen atoms (H_2) and one oxygen atom (O).

It is found on Earth in very large quantities, almost always with other elements that are dissolved in it. (It is the quintessential universal solvent, and its physical and chemical behavior changes when it contains dissolved substances.)

If we consider pure water, we know it has the following properties: It freezes at 0°C (32°F) and boils at sea level in an open container at 100°C (212°F). One liter of water (dm^3) at 4°C weighs 1 kg (at sea level). If we boil it in a closed container without air (or other gases), we will see that each temperature corresponds to a specific pressure. (This relationship occurs with saturated steam).

To melt 1 kg of ice, we need 80 kilocalories, and to heat 1 kg of water by 1°C, we need 1 kilocalorie (kilo = 1000, or 1000 "small" calories).

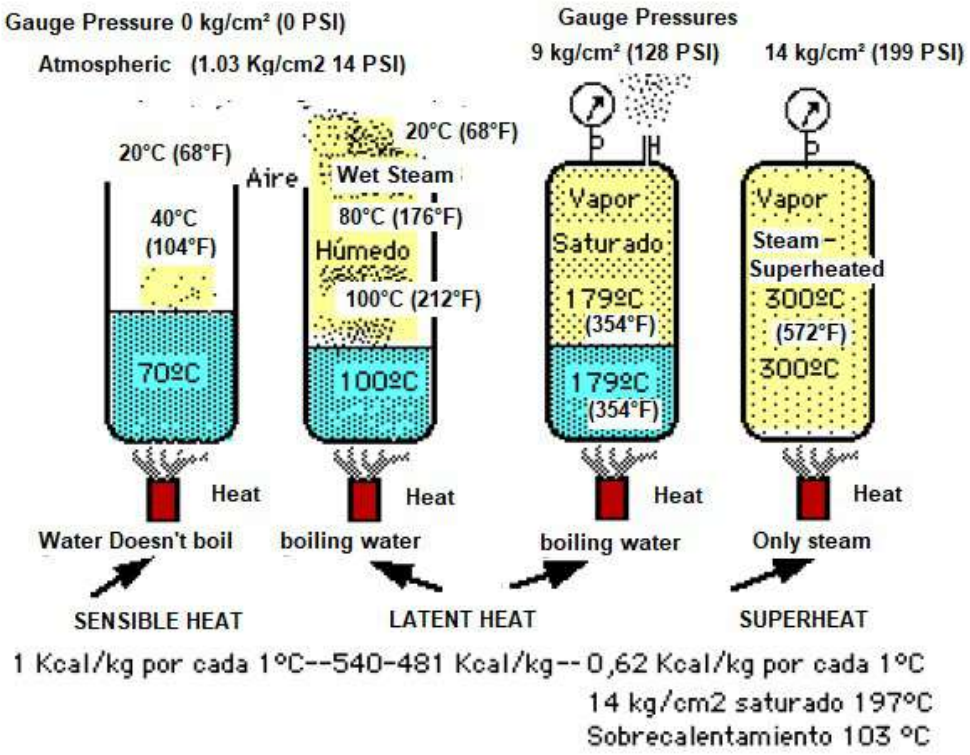
When we take a container with 1 kg of pure water and heat it from 0°C to 100°C (212°F), we will need approximately 100 kilocalories. This heat, which we can "feel" and which increases with temperature, is called sensible heat.

We will see that when we heat pure water in an open container (in the atmosphere and at sea level, see previous sketch), the water boils at 100°C (212°F). If we continue heating, we will see that the temperature remains at 100°C (212°F), but the water evaporates (transforms into steam).

This heat that transforms the water into steam is called latent heat (heat that is in the form of energy—that is, it transformed the liquid into a gas—steam—which, upon cooling, transforms back into the liquid—water—giving us that heat again).

Let's clarify what boiling means: this occurs when a large movement is observed within the water, caused by the rapid release of vapor bubbles. In other words, the pressure of the generated vapor

exceeds the pressure of the surrounding water and vapor. (Evaporation can occur even if the boiling point is not reached).



The atmosphere is composed of water vapor and gases (oxygen, nitrogen, etc.). This water vapor has a partial pressure corresponding to the temperature of this mixture, and the amount of vapor present in the atmosphere—forming ambient humidity (expressed in meteorology as % relative humidity)—comes from the evaporation of oceans, lakes, rivers, etc. There is a maximum (saturation, "dew point") for each temperature and atmospheric pressure.

If we seal the container and heat the water (allowing all the air to escape, pushed out by the steam), we will see that the steam, having no room to expand, begins to increase the pressure inside the container (the pressure inside before sealing is 1 atmosphere absolute, or 1.033 kg/cm² - 14.7 psi - and the gauge pressure is 0).

It can be observed that the temperature of the water and the steam is the same and that both rise in a correlated manner (each temperature corresponds to a specific pressure). If we cool and then reheat the container, these temperature and pressure values will

return to the same levels as before (provided there are no other gases mixed with the water vapor).

This steam that is generated and is in contact with the water is called saturated steam (dry or wet steam). In the case of boilers, because there is water circulation inside, by "carrying" tiny droplets, we can have steam that is not dry saturated, but saturated with moisture. This is called wet steam, and the total amount of steam (which we express as 100%) minus the moisture content, which represents its percentage by weight, is called the "Steam Title" (representing the percentage of dry saturated steam by weight).

If we heat a closed container of water (with a small amount of water), that is, if we manage to completely evaporate the water, the steam, upon receiving heat, will have a higher temperature and pressure. However, the temperature will be higher than the pressure in the previous case; this steam is superheated steam. (This steam is dry and can absorb water until it reaches saturation, lowering its temperature).

The relationship between the water temperature and the pressure of saturated steam in a boiler is found in the Saturated Steam Tables.

SATURATED STEAM TABLE

TABLAS DE VAPOR SATURADO

	pressure	temperature	total heat	water heat	steam heat	volume	
	presión	temperatura	calor total	calor agua	calorvapor	volumen	
PSI	ATA	C°	Kcal/Kgr.	Kcal/Kgr.	Kcal/Kgr.	m3/Kgr.	
0.7	0.05	32.55	611.3	32.55	578.9	28.7300	
2.8	0.20	59.67	623.1	59.61	563.5	7.7930	
7.1	0.50	80.86	631.6	80.81	550.8	3.3010	
14	1.00	99.09	638.5	99.12	539.4	1.7250	Presion atmosfera al nivel del mar 1.033 Kg/cm2 14.7 PSI
28.4	2	119.62	645.8	119.87	525.9	0.9016	
42.7	3	132.88	650.3	133.40	516.9	0.6166	
56.9	4	142.92	653.4	143.60	509.8	0.4706	
71.1	5	151.11	655.8	152.10	503.7	0.3816	
85.3	6	158.08	657.8	159.30	498.5	0.3213	
99.5	7	164.17	659.4	165.60	493.8	0.2778	
114	8	169.61	660.8	171.30	489.5	0.2448	
128	9	174.53	662.0	176.40	485.6	0.2189	
142	10	179.04	663.0	181.20	481.8	0.1981	Presion de trabajo 10 Kg/cm2 147 PSI
156	11	183.20	663.9	185.60	478.3	0.1808	
213	15	197.36	666.6	200.60	466.0	0.1343	
284	20	211.38	668.5	215.8	452.7	0.1016	

(Saturated steam table in imperial units at the end of the chapter)

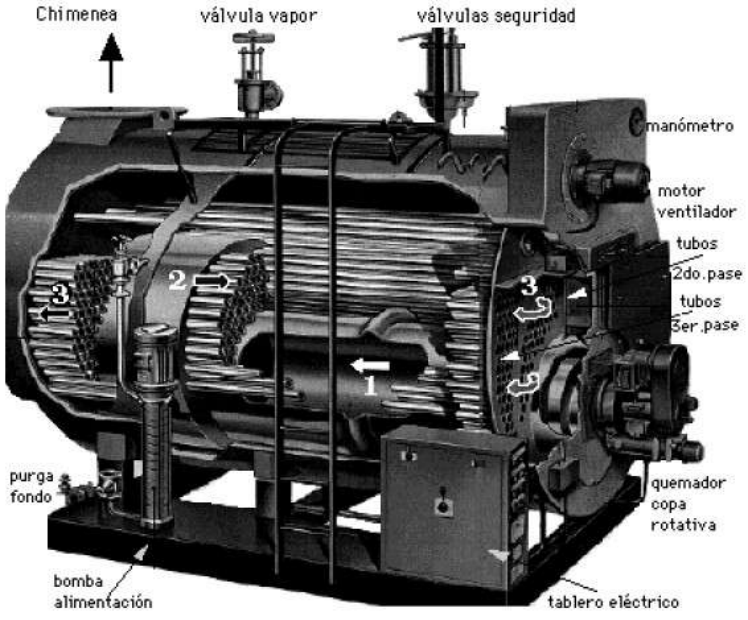
Example: Given that a pressure of 1 ATA = 1 kg/cm² (14.2 PSI) (not to be confused with atmospheric pressure, where 1 atmosphere is equal to 1.033 kg/cm²).

For a pressure of 11 ATA (Technical Atmosphere Absolute), which is approximately equal to 10 kg/cm² gauge pressure, or 156 PSI, the temperature is 183.2 °C for both water and steam.

To heat water to its vaporization temperature (183.3 °C) from 0 °C, 185.6 kilocalories per kg of water are needed, and to vaporize that kg, 478.3 kilocalories are required. In other words, to vaporize 1 kg of water at a pressure of 11 Atmospheres Absolute Technical (10 kg/cm² relative to 0 gauge pressure) starting from 0°C, we need a total of 663.9 kilocalories. These values are in the steam tables. See tables at the end.

This allows us to calculate the amount of heat needed to produce each kg of (dry saturated) steam at a given pressure, simply by knowing the boiler's operating pressure and the feedwater temperature:

Heat required to evaporate 1 kg of water = Total heat of steam - Heat of feedwater. (This heat will be greater due to heat losses in the boiler).



CALDERA HUMO TUBULAR DE 3 PASES

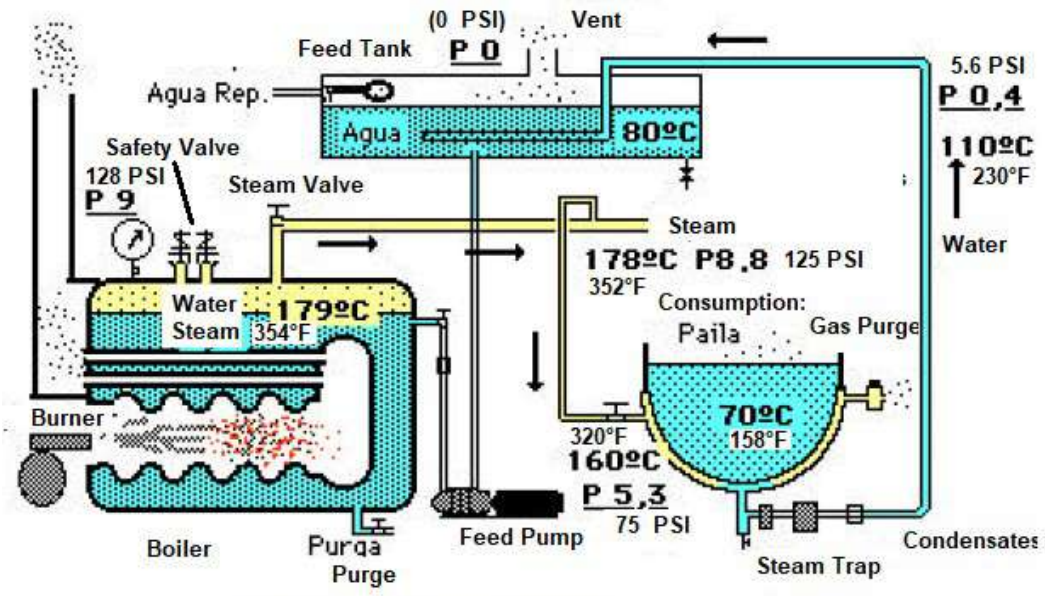
As the example shows, the most significant heat per kg is due to latent heat or heat of vaporization, which is typically used by condensing the steam at the point of use.

Just as knowing the pressure of saturated steam allows us to determine its temperature, knowing only its temperature will also allow us to determine its pressure. (Remember that saturated steam is steam that is in contact with the water that produces it and does not receive any more heat as it evaporates).

From the above, it follows that if we know the pressure of saturated steam, we can determine its temperature and the amount of heat it can provide where we use it:

Heat provided = Total Heat of the steam - Heat of the condensed water.

(The condensate is generally at a temperature above 100°C (212°F) because its pressure is higher than atmospheric pressure (it is called superheated water) - see table - and once at atmospheric pressure, it releases some of its heat, forming flash steam. This re-evaporation occurs to achieve equilibrium between the temperature and pressure corresponding to saturated steam (atmospheric pressure, since the feed or condensate tank is connected to the atmosphere).



water cycle and steam transporting heat

We see that in the cycle that water and steam undergo, their temperatures and pressures will be related as long as they are in direct contact (dry or wet saturated steam).

This relationship will only be altered if we heat the steam alone or produce a decrease in pressure by increasing the volume occupied by the steam without adding heat (as in the case of lowering the pressure with a pressure regulating valve).

We will normally find steam with moisture, but for practical purposes, we can consider it dry saturated steam. (The quality of the steam depends on the chemical and physical conditions in the boiler: the firing rate, sudden openings of fuel, pH, TDS, contaminants, etc.).

Saturated steam in imperial units:

CAMPBELL-SEVEY, INC.

PROPERTIES OF SATURATED STEAM

Steam Pressure PSIG/ Inches Hg	Saturated Temp °F	Sensible Heat BTU/lb.	Latent Heat BTU/lb.	Total Heat BTU/lb.	Specific Volume (liquid) cu ft/lb	Specific Volume (vapor) cu ft/lb
29.743	32	0	1076	1076	0.01602	3306
20	161	129	1001	1130	0.01640	75.32
10	192	160	982	1143	0.01658	39.21
0	212	180	970	1150	0.01671	26.80
5	227	195	960	1156	0.01682	20.38
10	239	208	952	1160	0.01692	16.49
15	250	218	946	1164	0.01700	13.88
25	267	236	934	1170	0.01714	10.58
50	298	267	912	1179	0.01743	6.69
75	320	290	895	1185	0.01765	4.91
100	338	309	881	1190	0.01785	3.89
125	353	325	869	1193	0.01802	3.23
150	366	338	857	1196	0.01818	2.76
200	388	362	838	1200	0.01847	2.14
250	406	382	821	1202	0.01873	1.74
300	422	399	805	1204	0.01897	1.47

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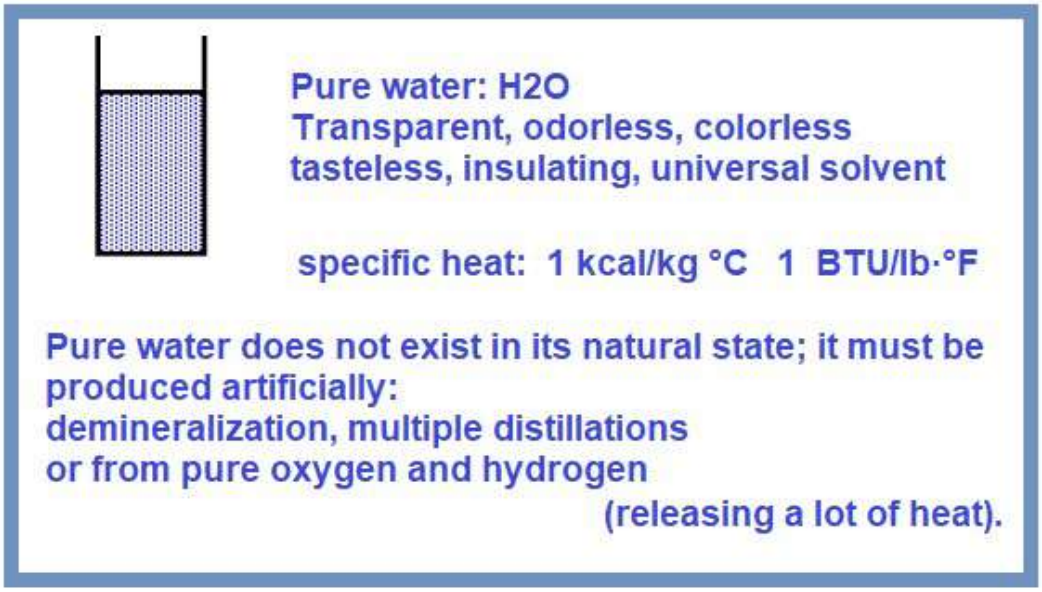
Abstracted from Thermodynamic and Transport Properties of Steam by ChemicaLogic Corporation

CHAPTER 2 Part 2: The water

THE WATER

We have seen that water is composed of a molecule made up of two hydrogen atoms and one oxygen atom. This water can be found in solid (ice), liquid (water), or gaseous (vapor) form. In our case, we will discuss water in its liquid and vapor forms.


Pure water: H2O
Transparent, odorless, colorless
tasteless, insulating, universal solvent
specific heat: 1 kcal/kg °C 1 BTU/lb·°F
Pure water does not exist in its natural state; it must be produced artificially:
demineralization, multiple distillations
or from pure oxygen and hydrogen
(releasing a lot of heat).

1- **Dissolved substances** that are either invisible or visible (due to color), and may or may not impart taste or odor.

(For example, table salt—sodium chloride—only imparts taste).

We will call these **Dissolved Salts sor Solids (T.D.S.)** because their molecules "mix" with those of water. These salts are measured in different ways to determine their quantity and identify them.

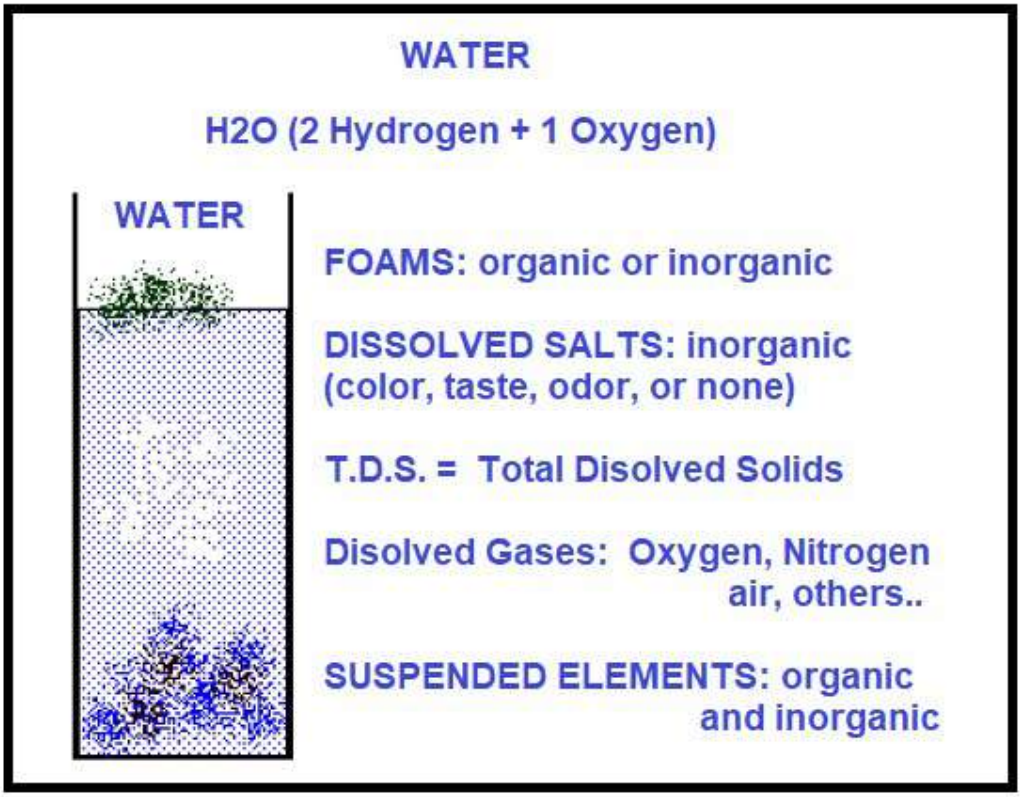
2- **Suspended solids** are materials that do not fully dissolve in water. Their molecules remain bonded, forming small bodies (or clumps) that are generally visible and often affect the color, odor, and taste of the water. (These solids generally include microorganisms that live in or contaminate the water.)

3- **Dissolved gases**, like dissolved salts, are integrated with water molecules, but their state is generally very unstable, as they depend heavily on the water temperature and the partial pressure of the gas at the surface. (They may impart taste, odor, and color, or none at all.)

Water for human use must be purified, both of microorganisms (which cause diseases) and of those elements that cause taste, odor, and color (generally, all of these are part of the suspended solids).

Water containing excessive dissolved salts or that are harmful to human health (toxic substances such as nitrites, chromates, pesticides, etc.) must also be treated to reduce or completely eliminate these salts.

Therefore, we can say:



(*) Organic compounds are primarily based on the carbon atom, and are the fundamental building blocks of life.

(**) While inorganic compounds can be formed from any other element on the periodic table, although they sometimes also contain carbon. Inorganics are found in minerals, salts, water, and gases such as carbon dioxide.

Rainwater:

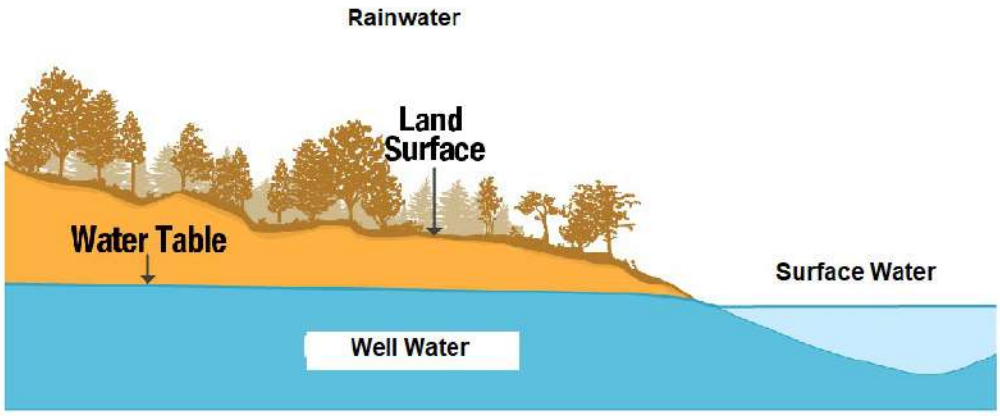
Very few dissolved salts, many gases (air, carbon dioxide, etc.), some suspensions (dust from the atmosphere and its microorganisms).

Surface water:

(rivers and lakes): Relatively few dissolved salts, quite a few gases and suspended materials (biological growth: microorganisms and agricultural products).

Well or Ground water:

Generally rich in dissolved salts, few gases, and low suspended solids content (almost none, except for sediment).



For human use, bacteriological purity is fundamental, as are chemical limits. It must be clean, without odors or tastes (nitrite being one of the elements harmful to human health, especially to young children).

Water for boilers must fundamentally meet the chemical requirements.

Let's see why:

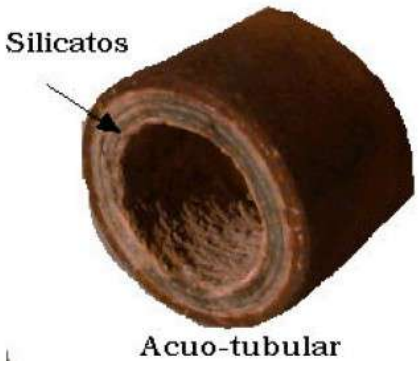
The water inside the boiler, due to its supply conditions and transformations caused by the increase in temperature or the increase in the concentration of its dissolved salts or suspended solids (due to evaporation inside the boiler, which leaves the salts and solids in the boiler water and the steam that comes out is "almost pure"), produces the following issues:

1-SCALES

this refers to the formation of a layer of "chemical" material that adheres to the walls of the heating surfaces, causing difficulties in the transmission of heat from the "fire" to the water, resulting in the metal overheating because the water does not "cool" it sufficiently – allowing the metal to "burn").

These scale deposits are generally formed by calcium and magnesium salts (two very common chemical elements in water – forming what we call "water hardness"). They commonly occur in water as dissolved salts in the form of highly soluble calcium and magnesium bicarbonates, decomposing inside the boiler into less soluble salts: highly insoluble calcium and magnesium carbonates, or their hydroxides, which are somewhat soluble.

Calcium carbonate (found in marble) can also contain magnesium carbonate, thus forming dolomite.



"Limescale" is calcium hydroxide and is partially soluble.

Due to heat and the chemical conditions of the water, magnesium bicarbonates tend to form magnesium hydroxide, a more scaling agent, forming "sludge" rather than direct scale, as its concentration increases.

Water can also contain other calcium and magnesium salts—of varying solubility—(generally sulfates and sometimes chlorides).

Sulfates often result from the water treatment process itself in urban water purification plants (in cities: when aluminum sulfate is used as a clarifying agent, it reacts with the water's natural alkalinity: calcium and magnesium bicarbonates).

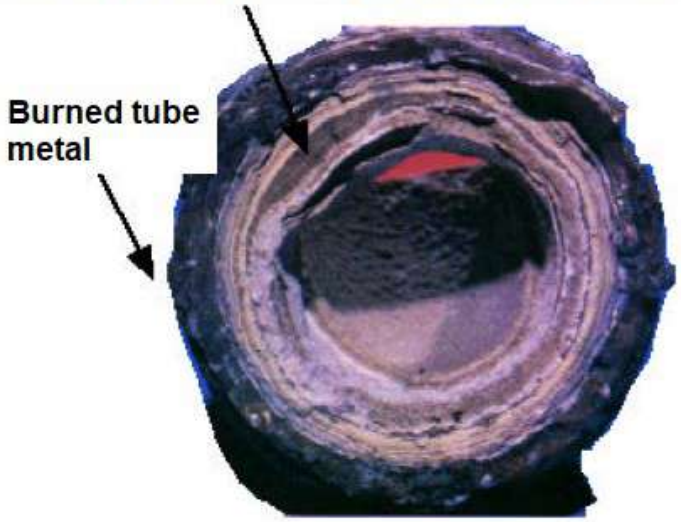
These sulfate scale deposits are extremely hard and difficult to remove. Sulfate scale is caused by an increase in its concentration inside the boiler, and because with increasing temperature it tends to precipitate, that is, to form a crystal that deposits on the hottest surface.

Silica (SiO2, or silicates, compounds that are present in water as salts or as a colloidal suspension) tends to form very hard scale deposits when it accumulates in boiler water.

Silica scale has a glassy or "sand", very hard and very difficult to extract mechanically and chemically, extremely insulating, not allowing heat to pass through to the water, even in small thicknesses.

Other times, the scale itself is "manufactured" by poorly done internal chemical treatments (generally due to the improper use of phosphates, polymers and purges, making these scales difficult to remove).

Example of different layers of scale according to stages of poorly performed chemical treatment

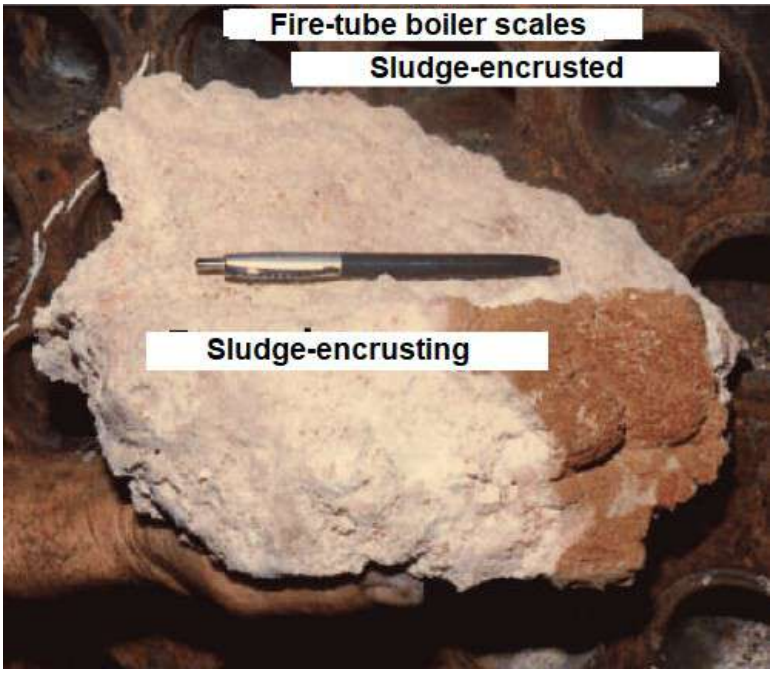


2-SLUDGES

We will define sludge as those salts that, once they precipitate, tend to agglomerate, forming suspended solids that, when combined, tend to deposit on heating surfaces or "bottoms," from which they cannot be removed by bottom purgue.

This sludge is formed by salts (of the type described above) and suspended solids that may come with makeup water or condensate, and from inadequate or nonexistent chemical water treatment.

The internal circulation of the boiler water plays a fundamental role in how this sludge can deposit and cause blockages to the cooling of the boiler metal. In fire-tube boilers without a cylindrical furnace (such as some recovery boilers or direct-fired wood boilers), the internal circulation between the tubes is upward, and a true "washout" of the tubes does not occur, allowing sludge to deposit on the tubes.



This does not happen when there is a cylindrical furnace. The cylindrical furnace (which acts as a circulation pump, washing the tubes) is one component. The other is the water-tube section of the boiler (especially in combustion chambers and flue gas return), where the sludge (which tends to descend due to gravity) is "pushed" upwards by the water circulation (which causes the sludge

to penetrate the tubes and allows its removal through the purge valves).

These tubes are generally ascending with a slight incline (especially in water-cooled grates or older "sectional" boilers).

Cleaning and periodic washing of the boiler are essential; that is, a semi-annual or at least annual hose cleaning, from top to bottom with a high flow of water.

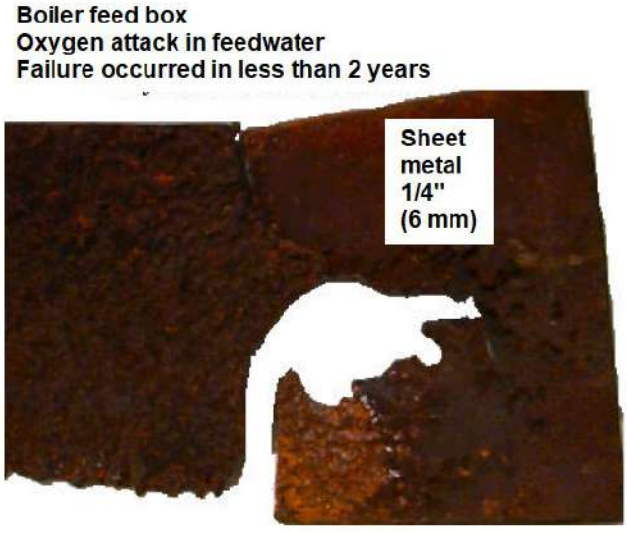
3- CORROSION

We will refer to corrosion as the attack on the metals of the boiler or system—steam and condensate lines, including equipment—causing pitting (perforations), generalized corrosion (attack on an entire area with metal loss, etc.).

The oxygen present in the water is the main cause and accelerator of corrosion processes in general.

We have exclusively chemical corrosions, but they are generally associated with electrochemical phenomena (temperature differences, dissimilar metals, stresses, pH, dissolved salts, oxygen, etc.).

It should be considered that corrosion is often caused by process products from the plant itself, or by products used in the treatment of the plant's drinking water, such as chlorine (which is generally used as sodium hypochlorite for water disinfection).



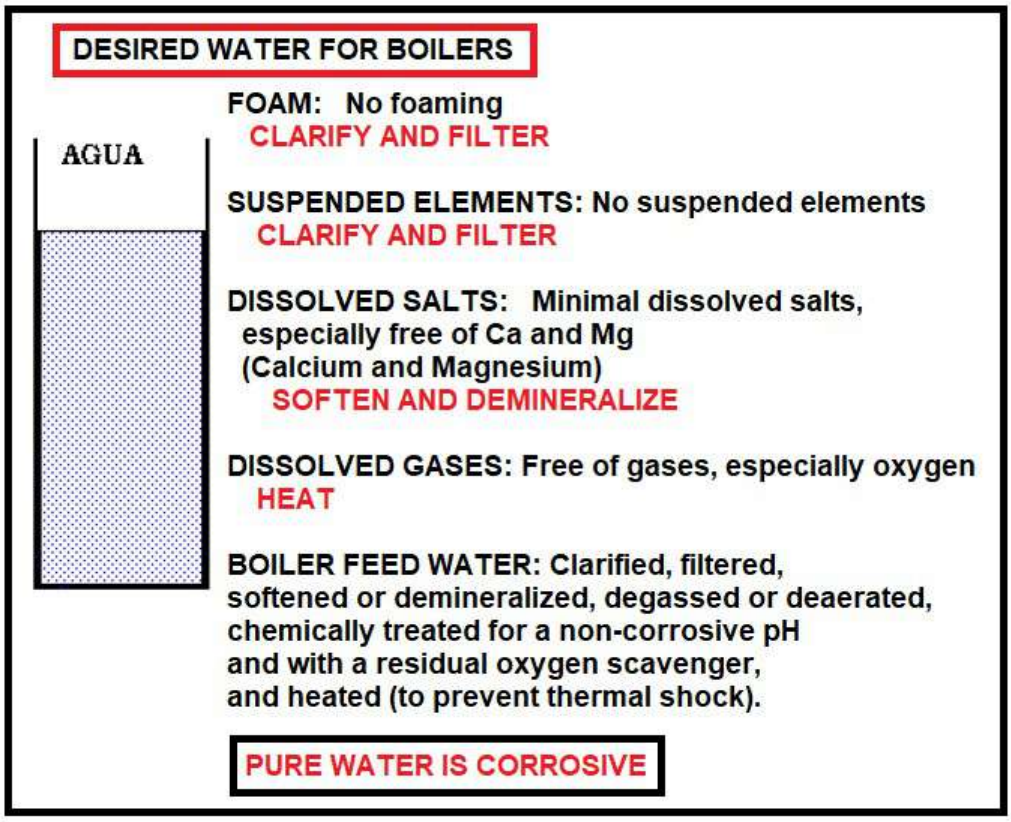
Chlorine is highly corrosive.

Unlike oxygen, chlorine can attack the boiler in any area (whether the boiler is running or stopped).

Removing chlorine from the makeup water is essential (although it can be chemically removed with sulfites, it is better to avoid using water that has had its chlorine removed by means of activated carbon filters).

Generally, oxygen attack occurs in boilers when they are stopped (manifesting as "pitting," or small perforations), usually in the steam tubes. However, as we will see below, in the boiler's water inlet system, when oxygen is released by heat and areas with different oxygen concentrations form, significant corrosion occurs (this is called "differential oxygen corrosion").

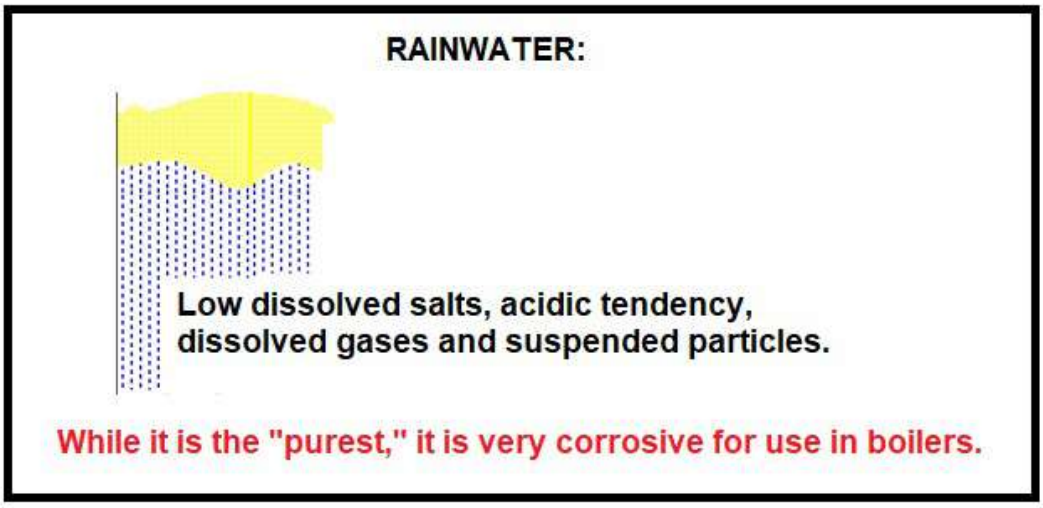
From the preparation of the water taken from a river (or a well, or distribution network, etc.) it must be treated as needed, since the problem of water is the whole "cycle" until its return as steam "condensate" when it returns to the feed tank.


DESIRED WATER FOR BOILERS
AGUA
FOAM: No foaming
CLARIFY AND FILTER
SUSPENDED ELEMENTS: No suspended elements
CLARIFY AND FILTER
DISSOLVED SALTS: Minimal dissolved salts, especially free of Ca and Mg (Calcium and Magnesium)
SOFTEN AND DEMINERALIZE
DISSOLVED GASES: Free of gases, especially oxygen
HEAT
BOILER FEED WATER: Clarified, filtered, softened or demineralized, degassed or deaerated, chemically treated for a non-corrosive pH and with a residual oxygen scavenger, and heated (to prevent thermal shock).
PURE WATER IS CORROSIVE

Methods for preparing different types of water for use:

The preparation of water for use depends on the type of boiler, operating pressure, and required steam quality.

Given the breadth of the topic, we will address the case of low-pressure boilers in general.


RAINWATER:
Low dissolved salts, acidic tendency,
dissolved gases and suspended particles.
While it is the "purest," it is very corrosive for use in boilers.

RAIN WATER:

This water is rarely used. It has the advantage of containing almost no salts (very few), but the high oxygen and carbon dioxide content of the air makes it highly corrosive. (In other cases, the salts present in the water form a protective "layer" or shield against corrosion; in this case, it doesn't form, making treatment necessary.)

To determine if water has a corrosive or scale-forming tendency, an analysis is performed using tables such as the Langelier Index, Ryznar Index, and Puckorius Index.

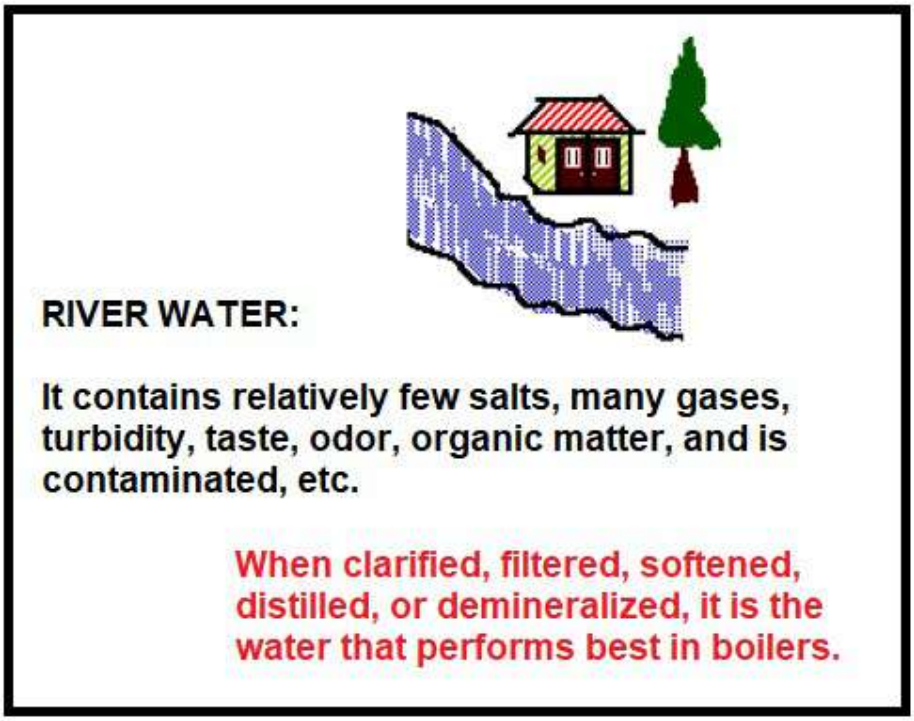
When treating rainwater for use in a boiler, it is essential to eliminate these gases (O2 and CO2). This can be achieved, firstly, by thoroughly heating the feedwater (or using a thermo-mechanical deaerator).

The solubility of gases in water is inversely proportional to temperature; that is, the higher the temperature, the less gas water can dissolve (we see this when opening a hot and a cold carbonated beverage; the hot one tends to overflow as the gas escapes quickly).

The residual oxygen must then be chemically removed (using sulfites, hydrazine, etc. - we must be very careful with the use of hydrazine because it is considered a "hazardous" substance).

The use of some of these chemical salts increases the salts inside the boiler, so the purge rate must be increased (sulfites).

Nowadays, rainwater is generally contaminated by environmental pollution, from chimney flue gases, but primarily by the large quantity of gases produced by the combustion of internal combustion engines, whether diesel or gasoline, both of which produce corrosive substances. But especially the gases from those who burn heavy fuel oil (which contains a large amount of sulfur).


RIVER WATER:
It contains relatively few salts, many gases, turbidity, taste, odor, organic matter, and is contaminated, etc.
When clarified, filtered, softened, distilled, or demineralized, it is the water that performs best in boilers.

RIVER WATER:

River water is the most common type of water used in boilers, as it is the water normally supplied by the state in Uruguay (treated by OSE).

These waters vary according to the time of year (evaporation) and rainfall, and have a high gas content (air, carbon dioxide, ammonia, etc.) due to being surface water.

The salt content is variable, but generally lower than in well water (which is why surface water is preferable to well water for boiler use; it requires less chemical treatment, less purge, etc.).

The "raw" river water must be treated (see the previous diagram): A product is added to the river water to remove suspended solids (generally aluminum sulfate, which reacts with the water's natural alkalinity: usually calcium and magnesium bicarbonates) in a mixer.

This causes the particles (along with microorganisms) to coagulate (neutralize the electrical charges that keep the suspended substances separate) and flocculate (clump together into a small sphere that tends to settle at the bottom of a container) so that they settle in a settling system (forming sludge).

From there, it is filtered (removing suspended materials that have not settled) and is also treated with a disinfectant (usually sodium hypochlorite) to eliminate any remaining microorganisms.

The pH is adjusted to prevent corrosion in the supply lines (soda ash or calcium hydroxide is added: slaked lime or quicklime; this replenishes the alkalinity that was consumed by the aluminum sulfate).

As we can see, these waters have only had suspended solids, odors, tastes, and microorganisms removed; the dissolved salt content has been increased, and the dissolved gases (oxygen, carbon dioxide, etc.) remain.

For use in boilers, we must remove scale-forming salts (those containing calcium and magnesium) or all salts (in the case of medium- and high-pressure boilers) and corrosive gases.

We can remove the calcium and magnesium salts that cause water hardness (or all salts) before using the water in the boiler or inside

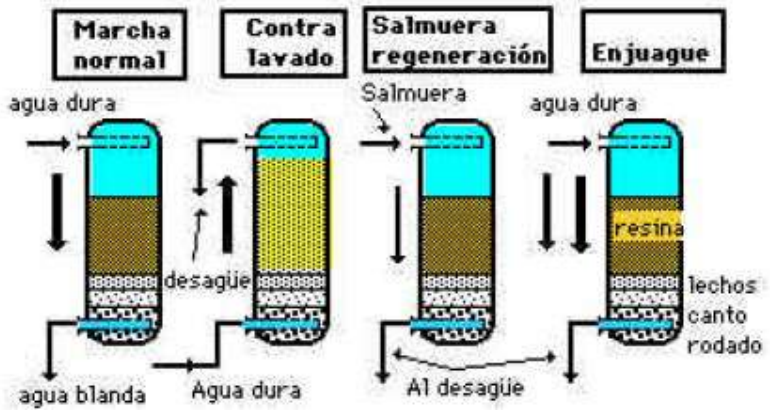
the boiler by transforming them into sludge that we can remove through the drains.

The most common method (in low-pressure boilers) to remove hardness before using the water is to use an ion exchanger (also called a water softener).

This device exchanges calcium and magnesium ions for sodium ions (small spheres charged with sodium take the calcium and magnesium ions and release a sodium ion as the water passes between them).

Once these spheres have depleted their sodium, they must be regenerated with sodium chloride (common salt).

When using a sodium-type ion exchanger (water softener), the total amount of salts remains the same because one type has been displaced by another. This water does not form scale but is highly corrosive because there is no salt to form a "protective" layer against the metal wall (scale, a stable oxide layer).



We can say that a water softener reduces the cost of treatment and keeps the boiler free of sludge. It is the first step in boiler water treatment (we will see others later); generally, the second step is internal chemical treatment.

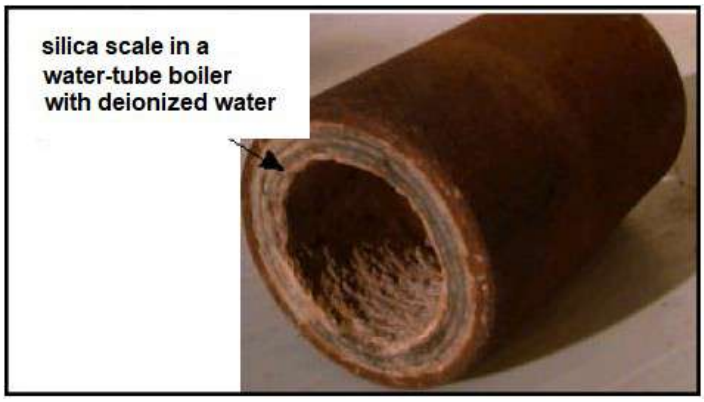
In the past, a large portion of the salts were removed through chemical precipitation (the salts reacted with other salts that were introduced, forming salts that precipitated and were no longer dissolved in the water, so they could be decanted and the water filtered, thus removing most of the salts). This method is expensive and requires constant chemical monitoring.

We can almost completely remove all the salts contained in water (both acidic radicals such as bicarbonates, carbonates, sulfates, chlorides, and alkaline radicals such as those of calcium, magnesium, sodium, or others) using ion exchange (with resins that exchange these radicals for H-hydrogen and OH-hydroxyl ions, the former regenerated with acids and the latter with soda). Both form H2O in place of the salts: water.

This water is called demineralized water. Its preparation is very costly, and it is mainly used in high- and medium-pressure boilers.

It is inherently corrosive (for the reason mentioned earlier regarding soft water). This water quality can also be achieved through distillation (that is, evaporating the water and then condensing it, leaving the salts concentrated in a solution that is purged; formerly, this was the only way to obtain salt-free water). (after several successive evaporations to achieve high purity).

This salt-free water is called distilled water (or, depending on the number of distillations, double-distilled water, etc.).



Currently, almost "pure" water (in which almost all salts are removed) is also obtained through filtration with a membrane (cellulose or polyamide filter) that only allows water to pass through (reverse osmosis, caused by water at relatively high pressure, in which almost pure water passes through at a certain percentage, with a percentage being discarded to maintain a maximum concentration on the salt side).

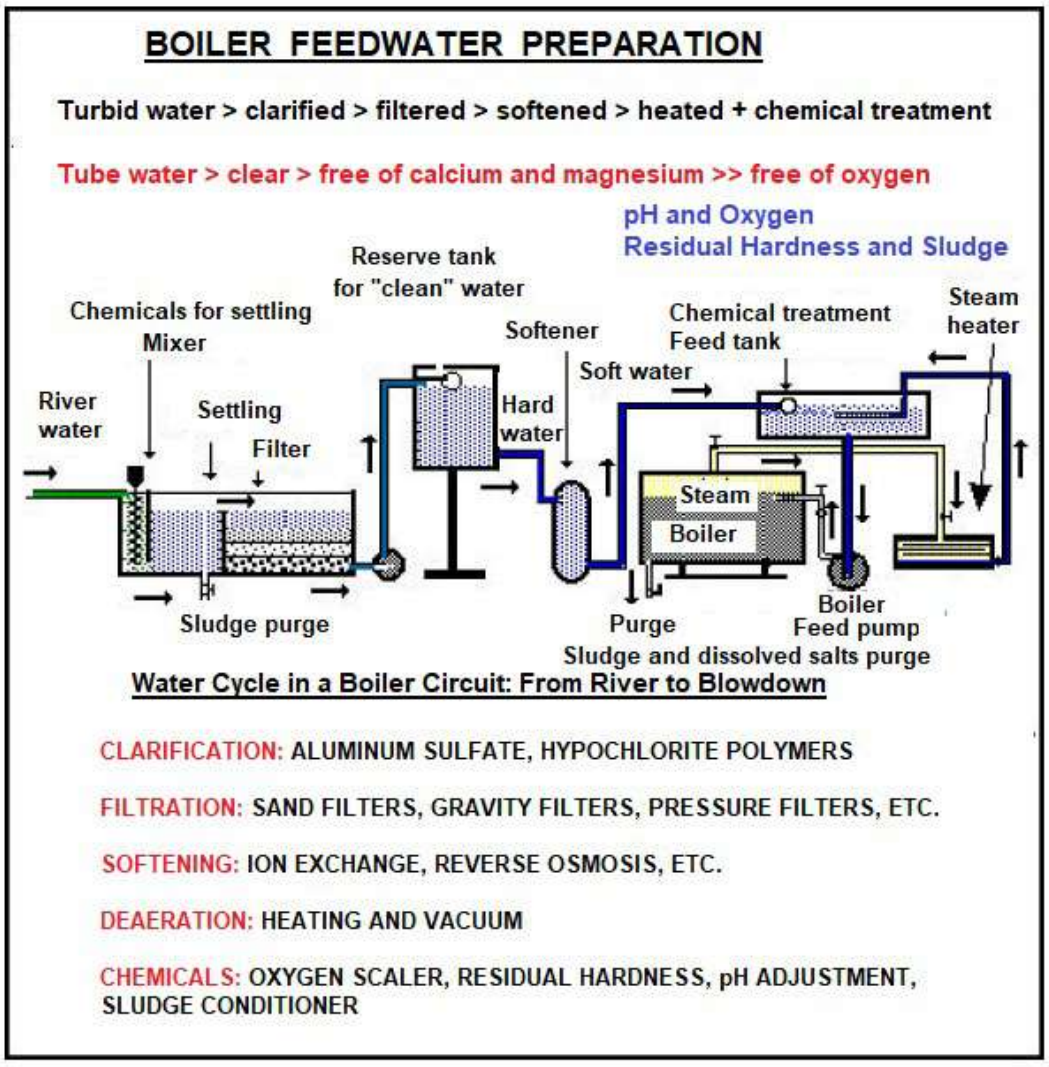
This water can be further purified by passing it through another filter and then further purified by ion exchange in a mixed bed of resins (a demineralizer with mixed resins, which are separated for regeneration).

In internal treatment, softening (removal of calcium and magnesium) is done exclusively with chemical products (which generally form sludge); like phosphates, polymers, etc., or non-sludge-forming salts such as EDTA (ethylenediaminetetraacetic acid), etc.

We see that purge plays a fundamental role in properly removing sludge (it is observed that dissolved salts decrease even with the addition of chemicals—due to precipitation—but because of the amount of sludge, it is necessary to keep the water "clear" with bottom purge).

Continuous purge removes the dissolved salts that accumulate as steam (pure water) escapes, leaving the salts behind.

Gases should be treated in the same way as rainwater.



Even if we use pure water, we must perform internal chemical treatment; otherwise, we will have corrosion problems, since pure water is corrosive (it tends to dissolve the iron that makes up the boiler).

We must never forget about silica (SiO_2, not in the form of sand, but as a soluble salt or in colloidal form; it can be removed in some of the treatments mentioned above, but not in sodium cycle softening). In boiler water, it can form very hard, insulating scale (almost impossible to remove once established), or it can be carried over in the steam, causing very serious problems in medium- and high-pressure boilers, such as deposits in the turbines (very hard scale on the steam turbine blades, causing low efficiency, severe vibrations, etc.) or in the steam superheaters (causing scale that isolates the tube from the steam, leading to tube burnout).

The higher the working pressure, the easier it is for silica to be carried away (since it tends to vaporize along with the water vapor).

WELL WATER:

This water generally contains few gases (though not always), but a very high concentration of salts—"hardness"—(generally free of suspended solids, sometimes sand).

It is very tempting for use in boilers, as it seems to be "free" and does not require the same treatment as river water for purification.

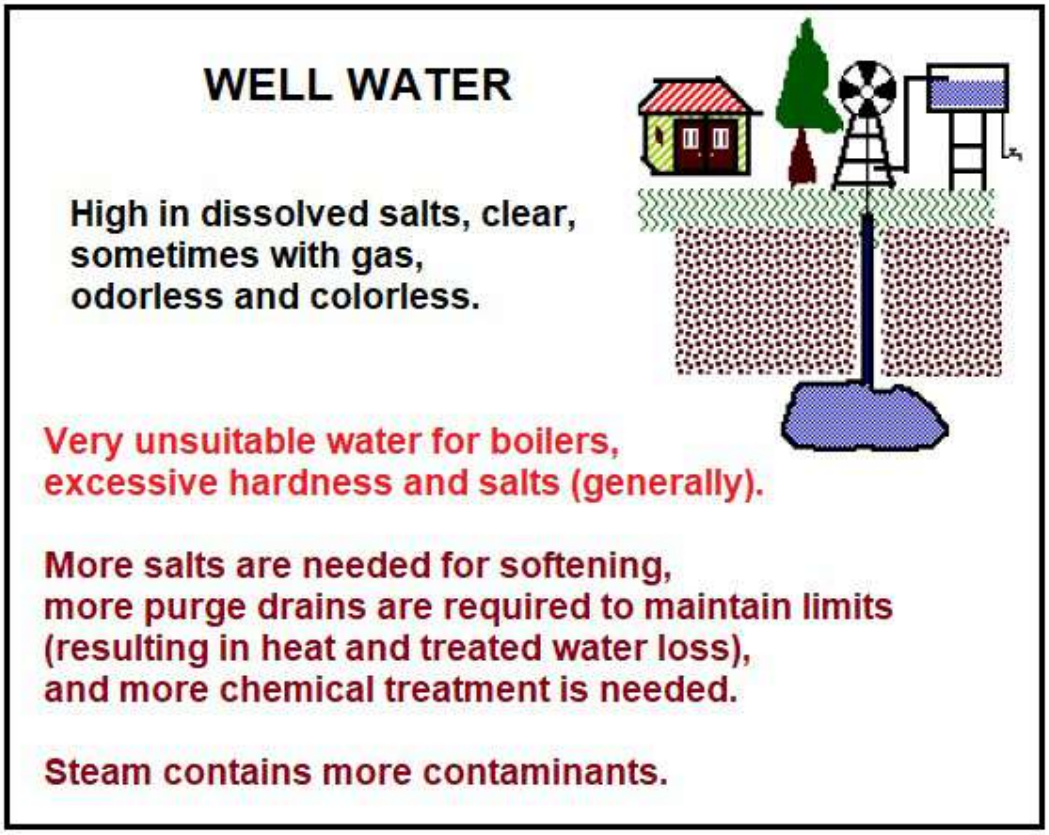
However, its use is generally inconvenient due to the cost of chemical treatment, because of the high salt content, which necessitates very high purge rates, large consumption of chemicals, and often problems with steam quality (causing "carryover" and CO_2, a highly corrosive element in the condensate).

We can say that well water varies depending on the area and depth of the well. Generally, in Uruguay, wells further south and east have high salinity (both temporary and permanent hardness), while wells north of the Río Negro and to the west have lower salinity (lower permanent hardness and salt content in general).

The high total alkalinity (calcium, magnesium, and sodium bicarbonates), responsible for temporary hardness, is due to the changes in its composition upon entering the boiler caused by heat.

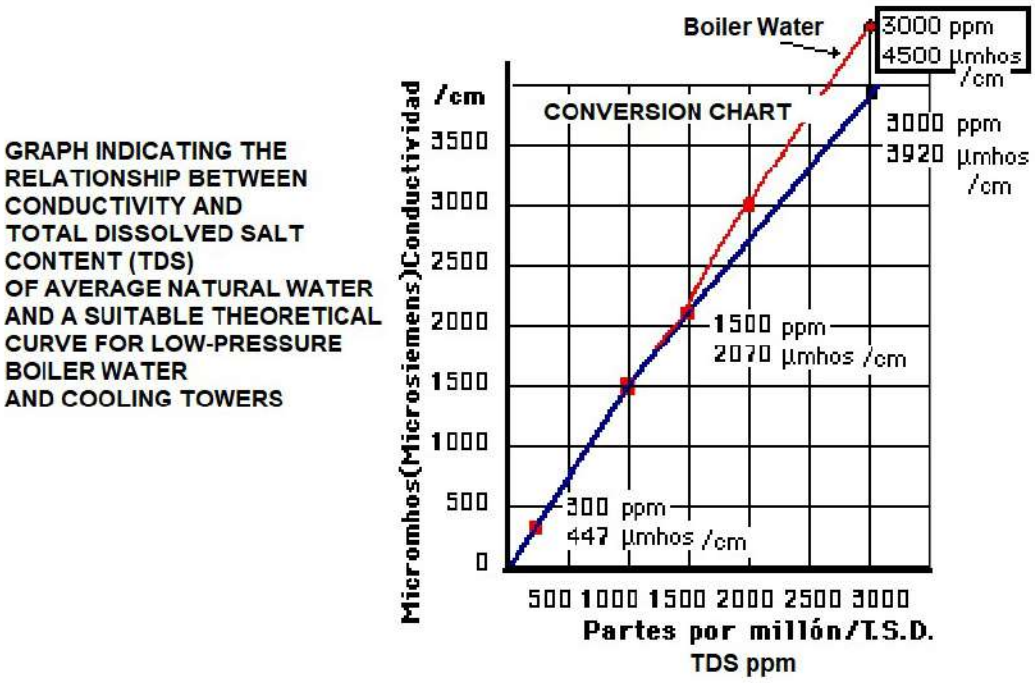
This alters the composition, breaking down soluble bicarbonates into insoluble carbonates (calcium and magnesium), and in turn, the carbonates, which are totally or partially soluble, into their corresponding hydroxides.

Sodium bicarbonate is soluble, while calcium and magnesium bicarbonates are less so, with the latter preferentially transforming into scale and sludge. This means that this type of water generally produces rapid scaling in boiler tubes if not properly treated.


WELL WATER
High in dissolved salts, clear,
sometimes with gas,
odorless and colorless.
Very unsuitable water for boilers,
excessive hardness and salts (generally).
More salts are needed for softening,
more purge drains are required to maintain limits
(resulting in heat and treated water loss),
and more chemical treatment is needed.
Steam contains more contaminants.

The presence of silica (SiO2) in salt or colloidal form in well water is one of the problems associated with its use. As higher steam pressure boilers are used, silica carryover can negatively impact the operation of superheated steam turbines. This silica deposits reduce turbine efficiency and can cause imbalances that may mechanically damage the turbine through vibrations. Furthermore, this deposited silica is very difficult to remove from the turbine runner blades.

Even in low-pressure boilers, the maximum silica limit in boiler water must be respected. Boilers scaled with silica salts (which are very hard and insulating, and can lead to boiler failure due to insufficient heat transfer and cooling) are very difficult to remove, whether by mechanical or chemical means. (In some cases, replacing the tubes has proven preferable to cleaning the boiler.)



GRAPH INDICATING THE RELATIONSHIP BETWEEN CONDUCTIVITY AND TOTAL DISSOLVED SALT CONTENT (TDS) OF AVERAGE NATURAL WATER AND A SUITABLE THEORETICAL CURVE FOR LOW-PRESSURE BOILER WATER AND COOLING TOWERS

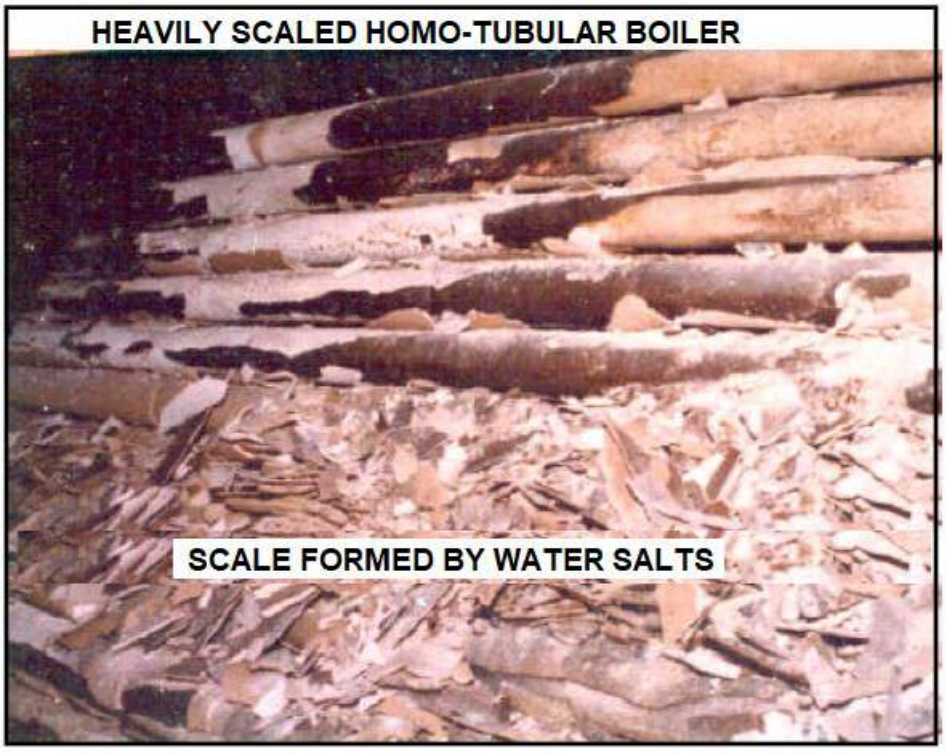
Problems Caused by Chemical Water Treatment:

Among the problems associated with water treatment, the most important is establishing the appropriate values for the analyzed parameters (alkalinity, Total Dissolved Salts - TDS, pH, phosphates, sulfites, chlorides, etc.). Even with the same boilers, pressures, and water quality, there can be differences in how steam is used:

A plant with high and rapid steam consumption tends to "carry over" the boiler water more easily. Therefore, parameters related to carryover must be lowered (alkalinity, hydroxide, pH, Total Dissolved and Suspended Solids, cycles of concentration, etc.).

In many cases, products that are "good" for eliminating a problem are added, but these same products can cause serious material damage or harm to health. (A boiler treatment takes years to properly evaluate, so be very cautious with changes and "miracle products").

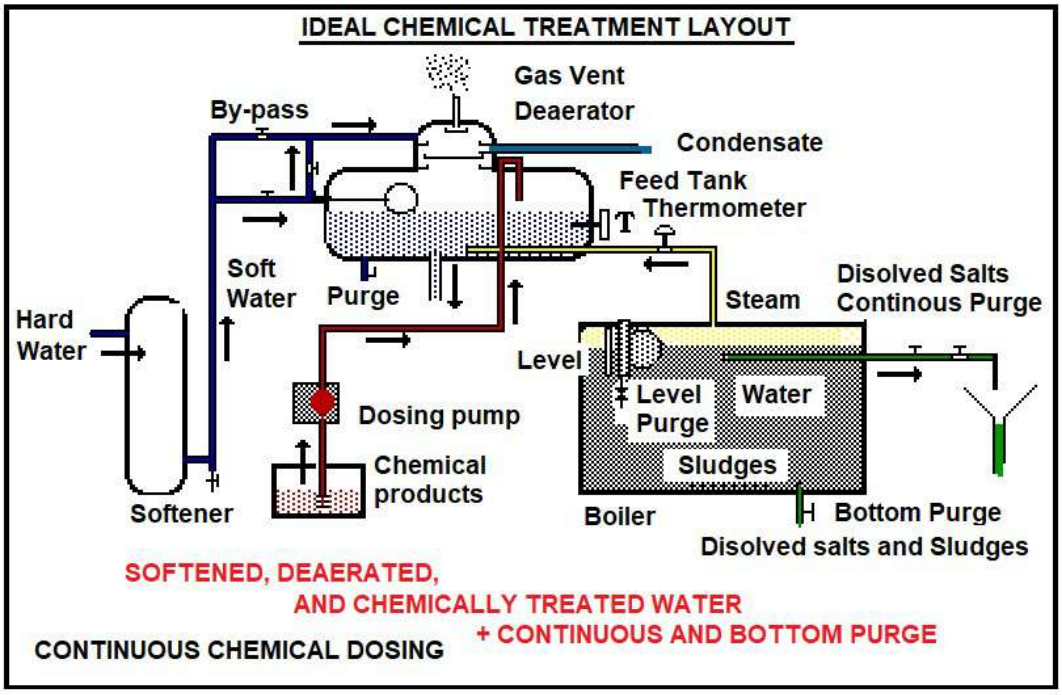
As a fundamental step, it is advisable to drain and open the boilers every 6 months, hose them down with pressurized water, and assess their condition (there is no better way; chemical analyses are relatively reliable).



Purges and how they are performed play a crucial role, because if they are not done in the correct quantity and manner, no matter how good the products used may be, the boiler or the process will be affected.

It is important to know not only which chemical products are necessary, but also how they will be used, their quantities, and the arrangement of auxiliary equipment for the treatment (water softener, dosing pumps, etc.). Scale buildup in fire-tube boilers can only be cleaned by chemical means (chemical cleaning with inhibited acids).

This process is generally divided into three parts: an alkaline preparation boil under pressure, a stage with inhibited acid (to prevent iron attack) at a specific temperature, and a third stage with an alkaline boil to neutralize the acid and with chemicals to passivate the material (restoring a protective layer to the surface attacked by the acid).



This entire process requires significant chemical and practical knowledge, as improper cleaning can damage the boiler or cause an accident. Water-tube boilers are cleaned chemically, but they can also be cleaned mechanically (with brushes, hydraulic, pneumatic, or electric turbines) since the inside of the tubes is accessible.

However, proper chemical cleaning is generally recommended. Afterward, a follow-up cleaning is necessary. "Sweeping" of scale and sludge from the entire interior of the boilers with a strong "hosing" and manual removal of fallen scale.

An ideal treatment is one that prevents corrosion, does not form scale or sludge, prevents boiler water carryover into the steam, and is economically viable.

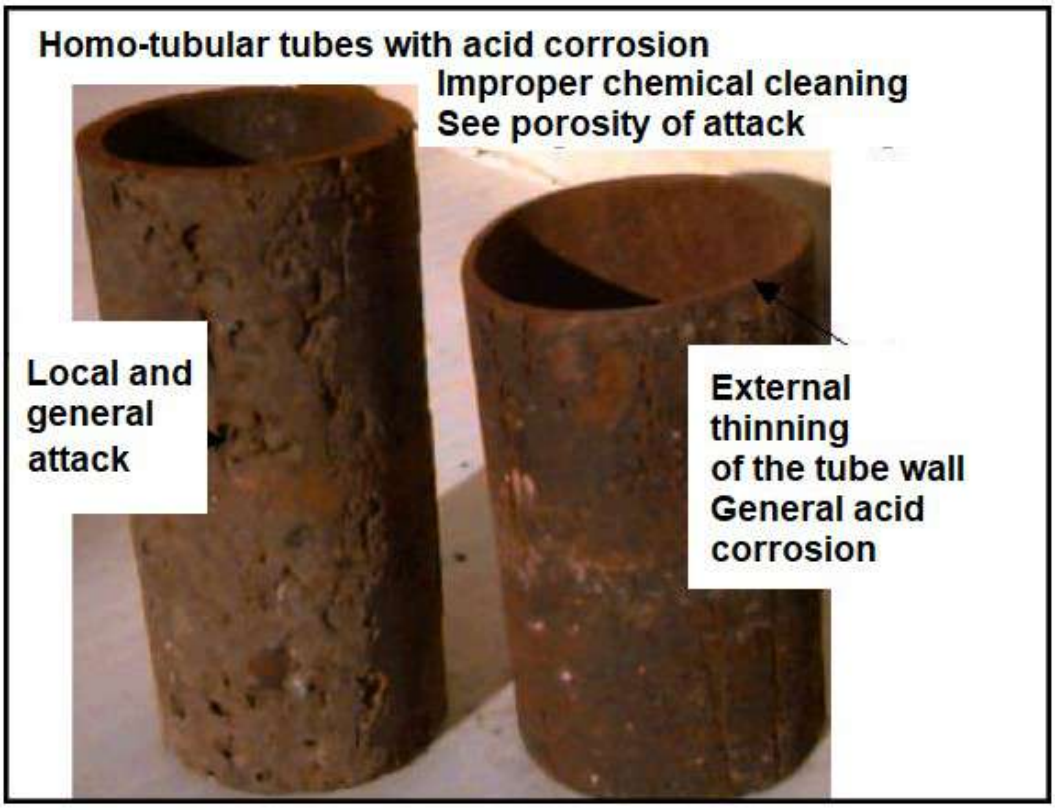
Removing all salts from the water (distilled or demineralized) would be ideal, but the cost is very high and control is quite difficult (corrosion must be controlled).

There can be problems with silica (SiO_2) if it is not removed properly, as this increases concentration cycles, can cause scaling, or lead to carryover.

Chemical treatment may be seen as a "cost," but it is actually an investment, since a boiler that does not receive proper chemical treatment is a boiler that will eventually have a problem that will not only result in the cost of repairing the boiler, but also in the cost of lost production (lost profits).

But even more importantly, boilers with inadequate chemical water treatment are generally more prone to serious accidents, ranging from a simple pipe leak to a complete explosion of the boiler casing or combustion chamber (both very serious accidents).

Poor treatment quality can lead to blocked level controls, which can cause boiler destruction due to insufficient cooling as the water level drops and the burner fails to shut off. This results in the metal being destroyed by the heat (with a high risk of explosion).


Homo-tubular tubes with acid corrosion
Improper chemical cleaning
See porosity of attack
Local and general attack
External thinning of the tube wall
General acid corrosion

Therefore, the ideal treatment (at low pressure, not in 100% of cases) is as follows:

1- Remove calcium and magnesium before the water enters the boiler.

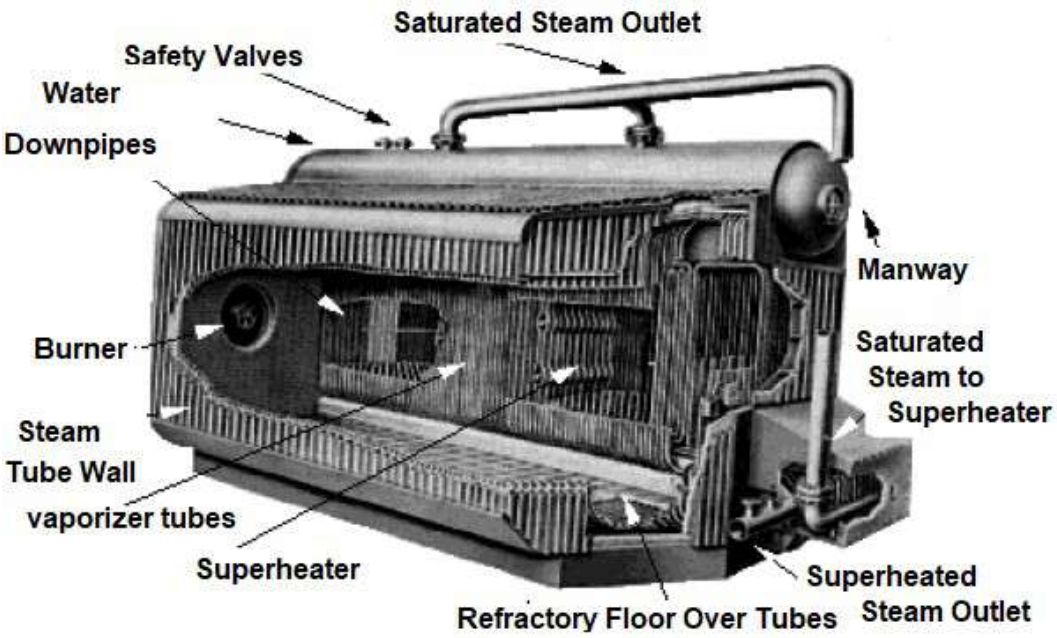
2- Remove gases (primarily oxygen). When a deaerator is not available, heat the water as close to 100°C (212°C) as possible (therefore, the feed tank must be 4 to 5 meters above the feed pump to prevent cavitation and allow for steam heating).

3- Internal treatment with continuous dosing to remove residual oxygen, maintain a level of products that eliminates residual hardness, and regulate the pH (low pH = corrosive acid, very high pH = corrosive due to instability of the protective oxide layer and water carryover in the steam).

4. An analytical system for monitoring (shift, daily, weekly, etc.; softener testing per shift = hardness), implemented on-site by the boiler operator.

5. A continuous purge system (including level checks every 4 hours), maintaining values within their maximum permissible limits. (It is important to be able to measure the flow rate per minute of the continuous purge, with a measurement point located downstream of the heat recovery unit for flash steam removal).

6. Recover as much condensate as possible; it is generally pure water. (Possible contamination in the condensate should be monitored through analysis.)



Modern FM Type Water-Tube Boiler

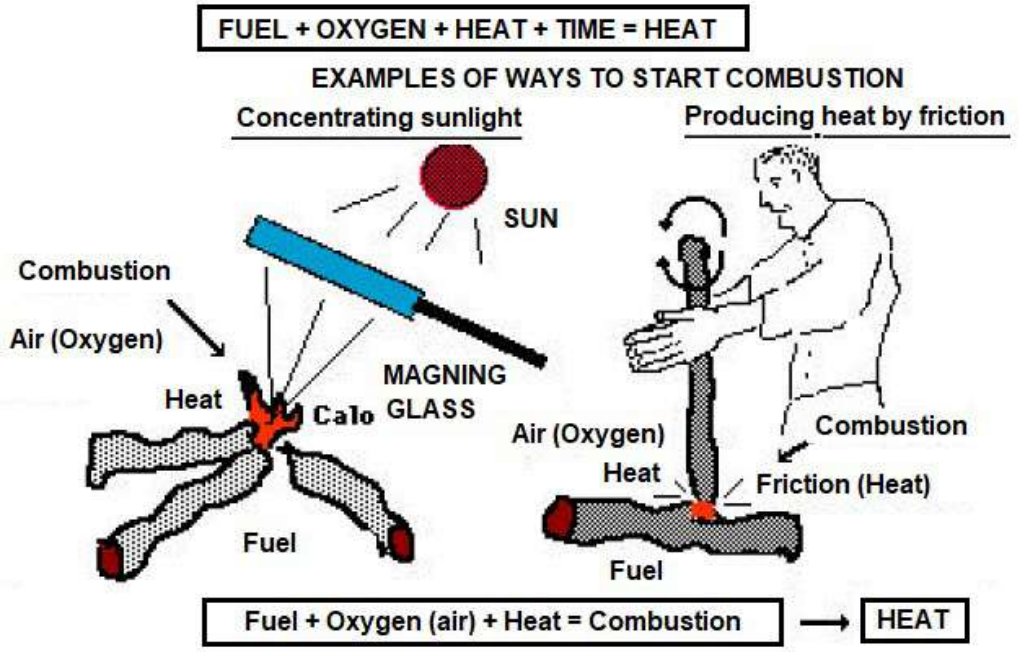
CHAPTER 3: The Fuel

3-Fuels and their combustion:

We will call fuels those products that we use to "burn" in boilers to produce heat, such as petroleum derivatives: heavy fuel oil, heating fuel oil, gas oil, LPG, piped gas; plant derivatives (cellulosic) such as: firewood, husks (rice, sunflower, etc.); fuels extracted from the subsoil in solid form such as coal (anthracite, lignite, bituminous coal, etc.) or gases such as: natural gas, gas produced artificially (coal-fired gasifiers, wood-fired gasifiers, etc.).

We see that we have solid, liquid, and gaseous fuels. Fuels are composed of elements that, when combined with oxygen in the air (rapid oxidation or combustion), produce heat, and elements that are indifferent to this oxygen (they do not react with oxygen, are inert, and are carried away with the hot gas or remain as ash).

For combustion to occur, the appropriate conditions must be met: a combustible element must be present, oxygen must come into contact with this element, and the chemical reaction (oxidation) must take place (that is, a catalyst or condition that facilitates this reaction is needed; in the case of boilers, it is the heat itself that allows this reaction to occur; in other cases, there may be an inducer of this initial oxidation (electric spark, friction, etc.) or a metal or metal oxide catalyst, etc., which then retains the generated heat).



A combustion time is also required, which varies according to the fuels and the conditions under which the combustion occurs.

We see that combustion requires three elements:

1- a fuel,

2- oxygen from the air

3- heat (to initiate the reaction).

To these conditions, we must add sufficient time for combustion to occur in a given space, and sufficient temperature to maintain it (if it cools down, the combustion will "go out").

The place where combustion occurs is called the hearth or combustion chamber, and combustion must be completed within this space.

Otherwise, we will see that for some reason, there was insufficient time or the conditions for complete combustion were not met; that is, partial combustion has occurred (some elements will exit the chimney unburned, meaning unoxidized or partially oxidized; this loss can be significant).

The elements that contribute heat in fuels are:

Carbon (C), Hydrogen (H), and Sulfur (S).

Carbon can bond with one oxygen atom (CO, called carbon monoxide) or with two oxygen atoms (CO2, called carbon dioxide). Relationship between atoms.

CO, or carbon monoxide, is a colorless and odorless gas. It is poisonous and its production as a result of combustion is undesirable, since the heat it produces is only 1/3 of what the same amount of carbon is capable of producing: 2,200 kcal per kg of carbon (8,700 BTU per pound of carbon) would be only 1/3 of 7,833 kcal per kg of carbon (14,500 BTU per pound of carbon burned).

This same CO, or carbon monoxide, can also be supplied as fuel (as in gas generators), burning it and obtaining the remaining heat from its complete oxidation.

Carbon dioxide (CO2) is a colorless and odorless gas. It is the desired product of carbon combustion found in chimney flue gases,

as it releases the maximum amount of heat in this state (7,833 kcal per kg of carbon, 14,500 BTU per pound of carbon).

CO2 is used to fizz carbonated beverages and to extinguish fires with pitchers (it is in a liquid state due to the pressure inside the pitcher, and upon release, it transforms into a cold gas that displaces the air—oxygen—extinguishing the fire).

Carbon dioxide (CO2) can be harmful to health (even though it's a gas we exhale) because it displaces air from the space it's in, being heavier than air. This is especially important to keep in mind when cleaning wine vats in cellars, as they are often full of this gas and must be ventilated before entering (asphyxiation can be fatal).

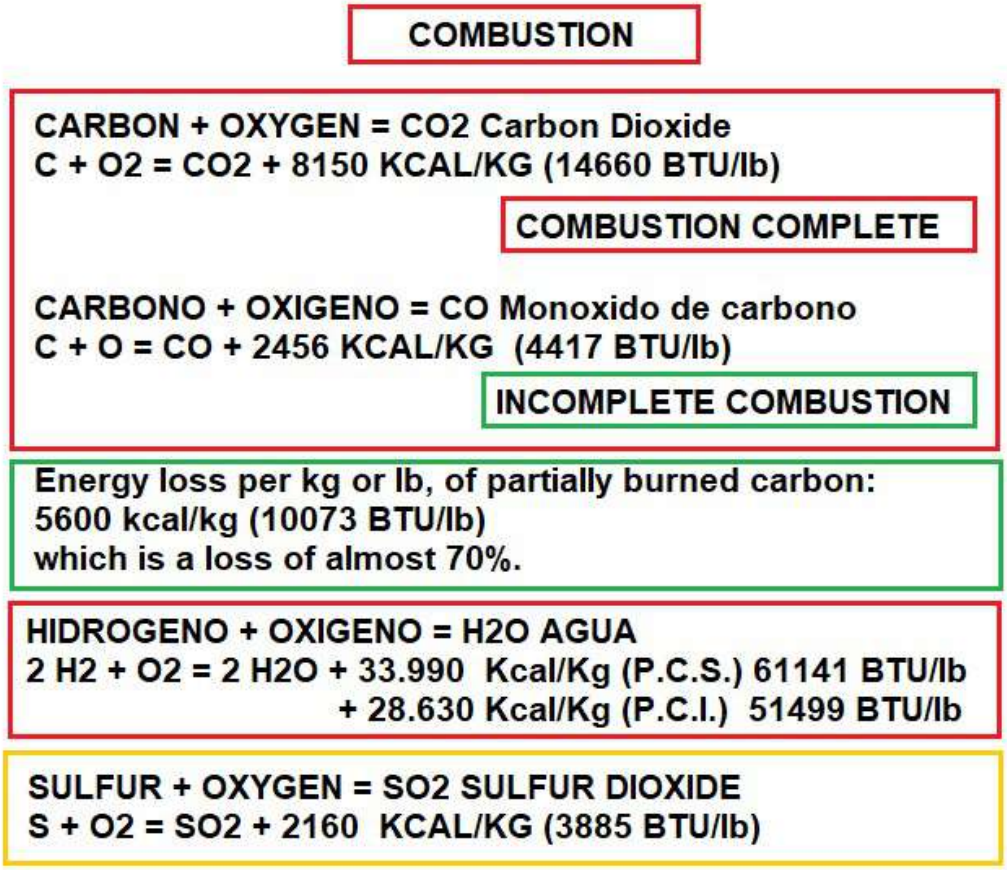
Hydrogen (H) combined with oxygen (O) produces water (H2O) (which will exit the chimney as water vapor) and heat (33,990 kcal per kg of H2 if we consider that the water formed condenses at 0°C; in imperial units, 61,127 BTU per pound of H2).

As we can see, it produces a large amount of heat per kg of hydrogen. Hydrogen torches produce high temperatures. It is used as rocket fuel, is highly explosive when mixed with air, etc.

Sulfur (S), when combined with oxygen (O), produces sulfur dioxide (SO2), a strong-smelling, poisonous gas that also releases heat (2165 kcal per kg of S).

This is an undesirable element in fuels because it produces little heat, and in the presence of water, it transforms into a corrosive acid: sulfuric acid (H2SO4), the same acid used in car batteries.

This acid typically attacks the iron in chimneys and recuperators (air heaters and economizers). Its concentration is highest in some types of coal and in some heavy fuel oils.


COMBUSTION
CARBON + OXYGEN = CO2 Carbon Dioxide
C + O2 = CO2 + 8150 KCAL/KG (14660 BTU/lb)
COMBUSTION COMPLETE
CARBONO + OXIGENO = CO Monoxido de carbono
C + O = CO + 2456 KCAL/KG (4417 BTU/lb)
INCOMPLETE COMBUSTION
Energy loss per kg or lb, of partially burned carbon:
5600 kcal/kg (10073 BTU/lb)
which is a loss of almost 70%.
HIDROGENO + OXIGENO = H2O AGUA
2 H2 + O2 = 2 H2O + 33.990 Kcal/Kg (P.C.S.) 61141 BTU/lb
+ 28.630 Kcal/Kg (P.C.I.) 51499 BTU/lb
SULFUR + OXYGEN = SO2 SULFUR DIOXIDE
S + O2 = SO2 + 2160 KCAL/KG (3885 BTU/lb)

There are other elements in fuels that do not undergo combustion, remaining in the home (ashes: silica, calcium, sodium, magnesium, etc.) or escaping through the chimney as ash, gases, or vapors (oxygen, nitrogen, water, etc.), absorbing some of the heat generated.

In the case of water, this absorbed heat is very significant, as the latent heat of vaporization of water is very high.

The water content of firewood (moisture) causes significant heat loss. For every kg of water (H_2O), approximately 600 kcal/kg (1080 BTU/lb) are lost. In fuels containing hydrogen (H), the water formed during combustion also absorbs heat. (However, H_2 releases a great deal of heat when it oxidizes, and for every 1 kg of H_2O, 9 kg of H_2O are formed; 1 lb of H_2O generates 9 lbs of water (H_2O).

The hydrogen-to-carbon ratio (H/C, the two elements that produce heat, not considering sulfur, which produces little heat and is undesirable) defines, primarily among liquid fuels, their combustion reaction. In other words, if one fuel oil has a higher hydrogen-to-carbon content compared to another (all other lighter fuels have this ratio: heating oil, diesel, gas oil, etc.), it will combust more easily and have a lower risk of soot formation.

This seems logical, given hydrogen's high heat output and high combustion rate, which improves the combustion of carbon, which is inherently slower (but the incandescent carbon also has a catalytic effect on combustion, accelerating it and shortening the flame length by increasing its combustion rate—a problem that arises in gaseous fuels with low carbon content and therefore low luminosity, where the flame length will be longer).

From what has been said above, we can see that the amount of heat that 1 kg of fuel can produce depends on whether we consider that water, which is present in the fuel or formed during combustion, to be in the form of steam (steam that goes up the chimney) or in the form of water (we cool the flue gases to 0°C - this is practically impossible).

This heat per kg of fuel is called the calorific value of the fuel. The Higher Heating Value (HHV) is calculated if we consider the water brought in and formed at 0°C (condensed water and combustion gases at 0°C), and the Lower Heating Value (LHV) is calculated if we consider the heat remaining after evaporating all the water brought in and formed (evaporated water, combustion gases, and steam at 0°C).

LHV = HHV - kg of water x 600 kcal/kg (practical value of heat of vaporization) or x 1079 BTU/lb

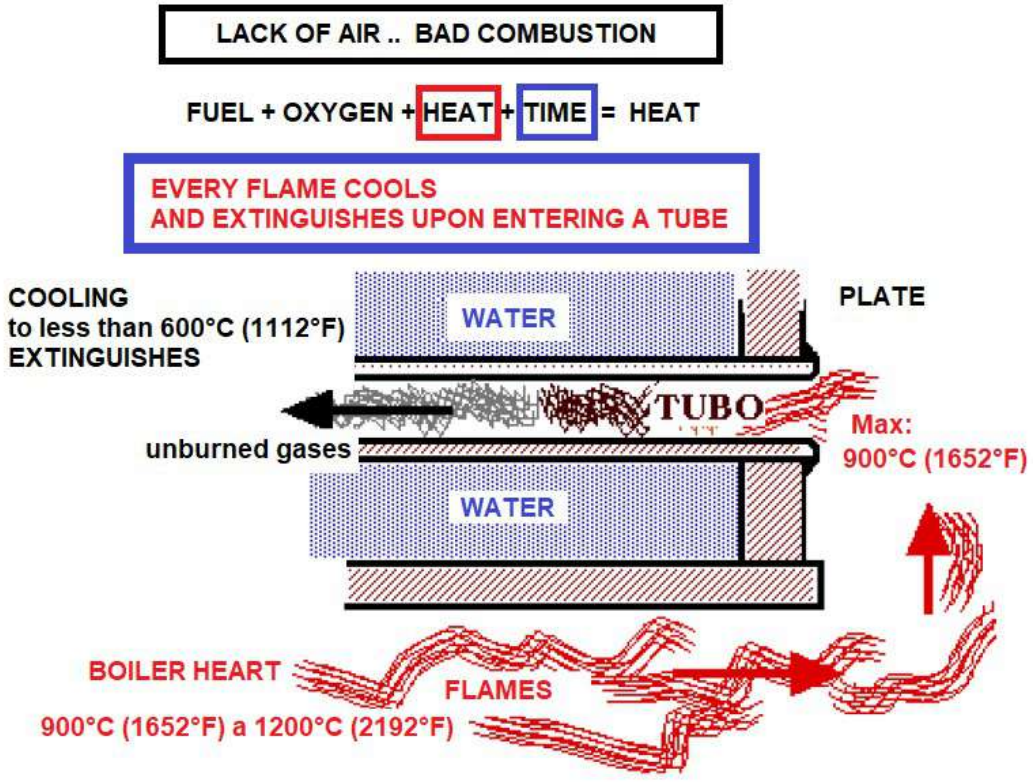
The air we use for combustion is composed of oxygen (21% by volume) and nitrogen (79% by volume, a gas that does not participate in combustion, but which, when heated, carries heat up the chimney). It also contains other gases of little numerical significance that do not participate in combustion (argon, neon, helium, etc.).

AIRE (Atmosfera)
Oxigeno: O2 ..... 21 % en volumen .. 23% en peso
Nitrogeno: N2 ..... 79 % en volumen .. 77% en peso

En el nitrogeno N2 consideramos otros gases que contienen el aire y que no intervienen en la combustión (aprox. 1%).

Since the Earth's atmosphere at sea level maintains this oxygen-to-nitrogen ratio (there are other gases in very small quantities), and since each fuel contains specific amounts of carbon, hydrogen, sulfur, etc., the combustion product (flue gases) has a ratio specific to each fuel. This ratio is unique for each combustion condition. (See the Ostwald diagrams in later chapters.)

To achieve complete combustion, we must ensure that every oxygen (O2) molecule comes into contact with every fuel molecule and that the temperature is sufficient for combustion to occur (oxidation, the fusion of oxygen atoms with hydrogen, carbon, and sulfur atoms). To achieve this, we will need more air than the **minimum or stoichiometric** amount required.



This excess air (called **"excess air"**) is a necessary evil, since any excess air we heat will escape through the chimney, carrying away heat unnecessarily.

Therefore, we must try to ensure that the fuel and air mix as intimately as possible, adding only excess air **to achieve complete combustion** (so that no fuel remains unburned), but this excess should not be too high, as it carries heat away through the chimney.

Since the composition of flue gases varies depending on the fuel, measuring their composition allows us to determine the amount of excess air being used.

For example, if we were to burn fuel oil and measure the oxygen in the flue gases, we would have three scenarios:

1- **No oxygen (insufficient air):** incomplete combustion (generally black smoke) or complete combustion (practically impossible, as this would represent stoichiometric air).

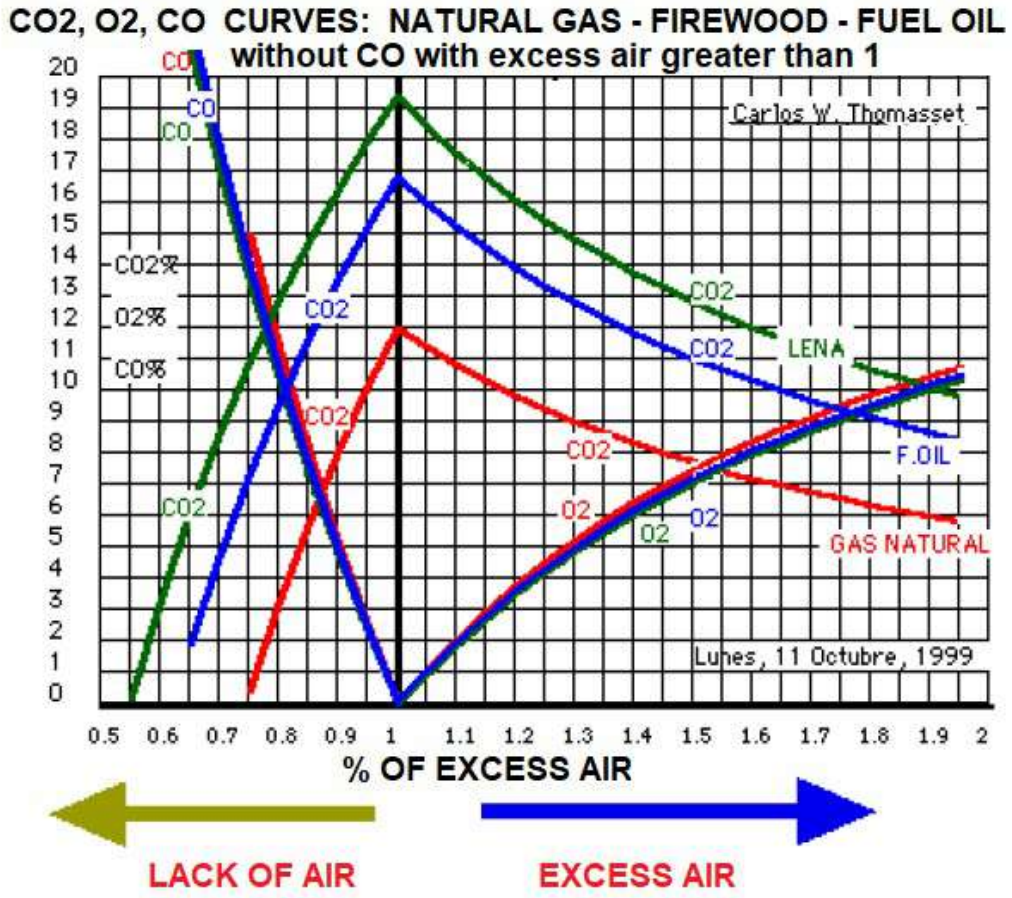
2- **A certain percentage of oxygen and no carbon monoxide (excess air):** combustion can be good or poor (smoke, soot, due to insufficient mixture or temperature).

3- **A certain percentage of oxygen and carbon monoxide: poor combustion** (incomplete combustion, generally present smoke, soot, etc.).

The presence of smoke in chimneys was always a helpful indicator of combustion quality, but this is now entirely insufficient, since the burning of gases and wood (biomass) does not produce the smoke in the chimney that can serve as a guide for combustion.

Burning fuel oil (heavy and light) is a good indicator (as is coal). The gases and combustion of cellulose fuels have led to the need for combustion control to be carried out using instruments, both to determine the necessary excess air and to detect unburned gases (which are a waste of energy and a significant source of environmental pollution).

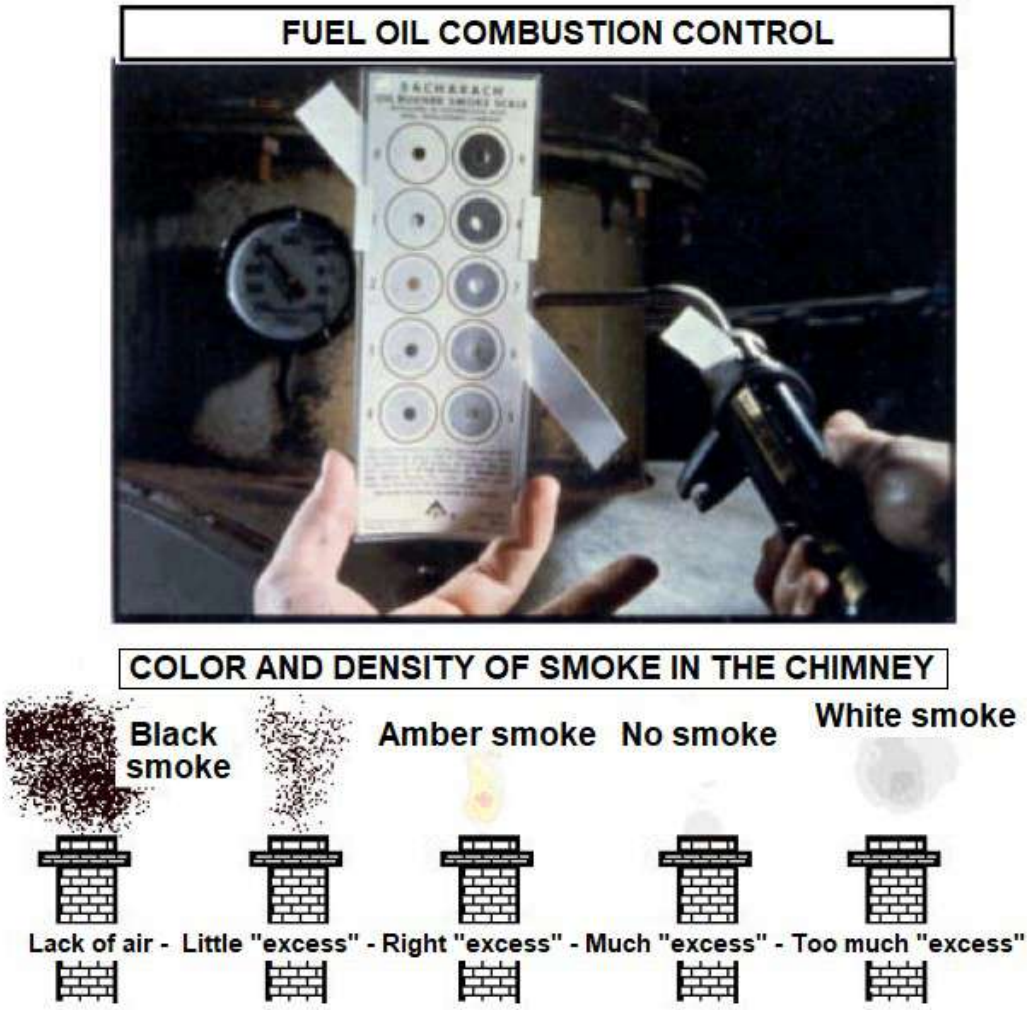
We will see that the color and shape of the flame is a way to determine the combustion result, but this varies from one fuel to another, with fuel oil being the most noticeable.



A certain amount of excess air is always needed for complete (or near-complete) combustion.

The greater this excess air, the greater the fuel loss.

Each fuel and burner type has a minimum excess air requirement, as unburned gases or soot appear below this level.

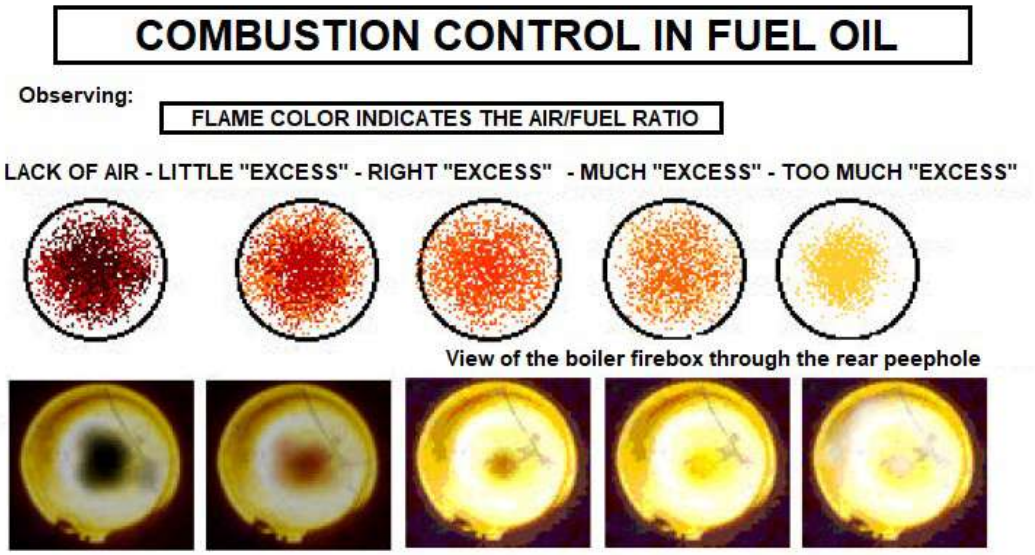

FUEL OIL COMBUSTION CONTROL
COLOR AND DENSITY OF SMOKE IN THE CHIMNEY
Black smoke
Amber smoke
No smoke
White smoke
Lack of air - Little "excess" - Right "excess" - Much "excess" - Too much "excess"

Soot:

Carbon in the form of coal particles, usually accompanied by smoke. In case 2 (no smoke and excess oxygen), we can determine the excess air without needing other values, since each excess of oxygen corresponds to an excess of air. Knowing the fuel composition will make the measurement more precise. See Ostwald diagrams next chapters.

The problem is that some fuels do not produce visible smoke or soot (rather, the incompletely burned carbon is released as CO - carbon monoxide - or other organic compounds). These fuels, which are difficult to soothe, include firewood, natural gas, and petroleum-derived or artificial gases.

In fuel oil and coal, smoke control, both visually and with instruments, shows us a series of combustion problems, including a lack of “excess air” (there should be a little more than the minimum air required, depending on the type of fuel and the type of burner), but the presence of smoke is not only due to a lack of air, but also to other problems, such as atomization, the temperature of the fuel, the furnace, the degree of combustion, burner failures or failures of the air and fuel mixing system, etc.


COMBUSTION CONTROL IN FUEL OIL
Observing:
FLAME COLOR INDICATES THE AIR/FUEL RATIO
LACK OF AIR - LITTLE "EXCESS" - RIGHT "EXCESS" - MUCH "EXCESS" - TOO MUCH "EXCESS"
View of the boiler firebox through the rear peephole

The color and shape of the flame when burning fuel oil gives us a clear indication of what is happening with combustion. This is complemented by observing the smoke, but measuring the flue gases (CO_2, O_2, and CO) provides a better way to diagnose the combustion process.

The other gas we can measure in the flue, and whose percentage indicates excess air, is carbon dioxide (CO_2).

<u>If the amount of air were the minimum necessary (stoichiometric air), there would be a maximum CO2 content characteristic of each fuel</u>:

approximately 16% on a dry basis for heavy fuel oil,

20% for cellulosic fuels,

11.5% for natural gas, etc.

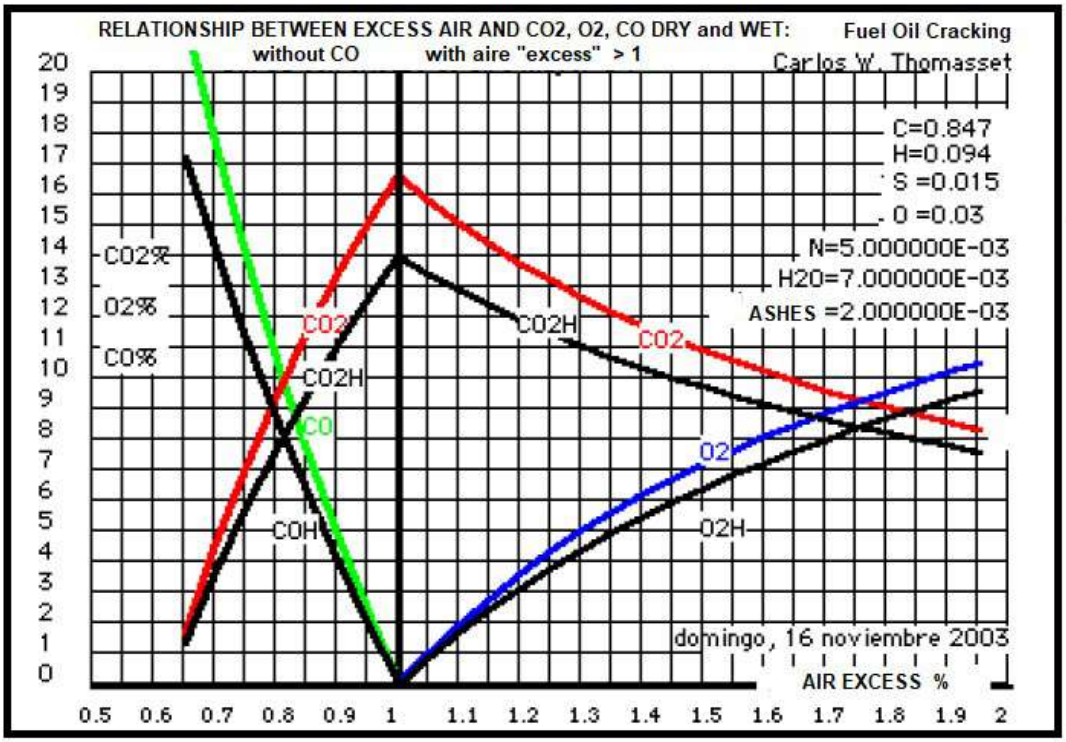
As the excess air increases, the percentage of CO2 in the gases decreases because the gases expand due to the increased air content. (This does not mean that less CO2 is produced, but rather that it is diluted).

If we determine the percentage of excess air based solely on the percentage of CO2, for the result to be accurate, there must be no presence of carbon monoxide.

When we measure the percentage of carbon monoxide (CO) and the percentages of oxygen (O2) and carbon dioxide (CO2), we can correlate the three measurements and determine the excess air without needing to know the fuel composition. (Case of ORSAT, detailed in Chapter 5).

Measuring flue chimney gases is crucial, as it provides information on combustion quality and excess air. Both of these represent energy losses that must be minimized in the boiler.

The % measurement of flue gases may be referred to on a dry basis (i.e., condensing the moisture of the flue gases - the most common measurement) or on a wet basis (i.e., taking into account the moisture of the flue gases).



The easiest measurement to perform is that of carbon dioxide (CO2), for example, with the FYRITE device (Chapter 5), which works by absorbing the gas in potassium hydroxide.

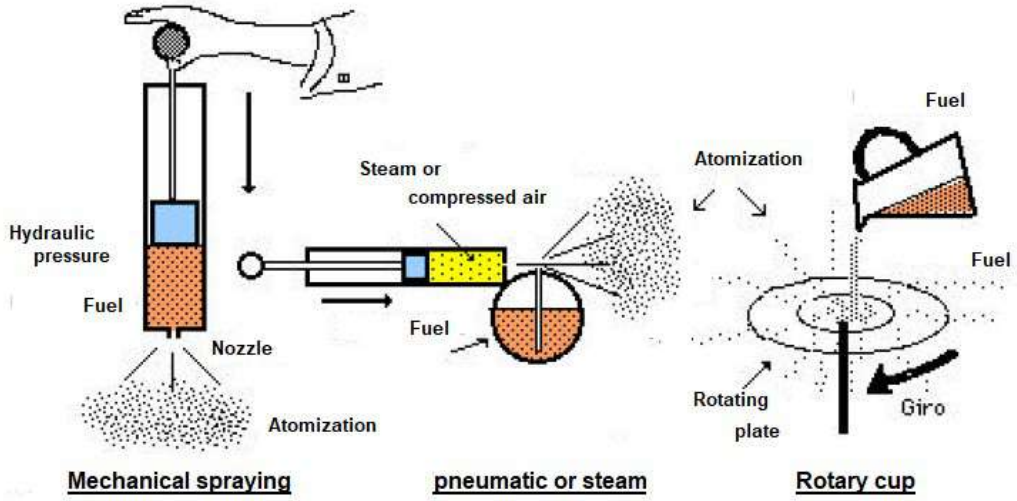
When we want to measure all three gases (CO2, CO, and O2), the simplest chemical absorption device is the ORSAT (Chapter 5).

Afterward, measurements can be taken with electrically or electronically operated equipment: electrochemical cells (O2), catalytic cells (CO), dissipation bridges (CO2), etc.

Not only carbon monoxide (CO) can be present as unburned gas in flue gases; other gases (hydrogen, H2, or volatile organic compounds) may also be present, but for practical purposes, they are all treated as CO. Generally, when CO is detected, these combustible gases may also be present.

We see that fuels are solid, liquid, or gaseous. To achieve good combustion, we need the fuels and air to mix intimately. The best way to do this is to gasify (volatilize) them: gaseous fuels are mixed directly, liquid fuels are pulverized (atomized), and solid fuels are heated in pieces (primary combustion) so that they volatilize.

But it must be clear that, even though the fuel is a gas, no matter how much it is mixed with air, there must be sufficient temperature (heat) and time for its complete combustion (oxidation) to take place.

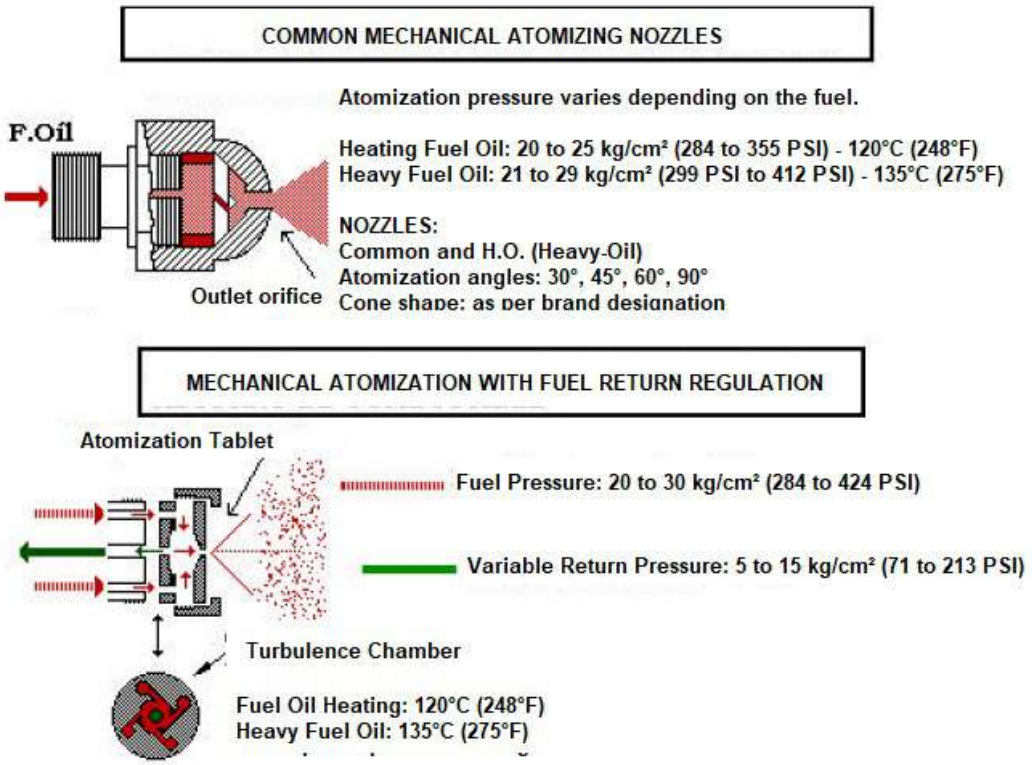


Therefore, we will have: liquid fuels will be atomized in burners that use the following methods: steam-assisted atomization (using steam to propel the fuel in the form of very small droplets), pneumatic atomization (using pressurized air for the same purpose), mechanical atomization (using high discharge pressures in orifices called nozzles, tips, or nozzles, whose internal shape allows for the formation of a very fine spray upon release), and rotary cup atomization (atomizing using centrifugal force).

Light fuels such as diesel and gas oil are typically used with steam-assisted or mechanical atomization burners as they come (unheated).

Because heavy and medium-heavy fuel oils have difficulty flowing through pipes due to their thick, pasty consistency (high viscosity) when cold, they need to be heated to different temperatures to facilitate their transport through the pipes and pumps, as well as to atomize them. This heating depends on the type of fuel oil and the type of pump, pipes, and burner being used.

This heating can be done with steam heaters or electric heaters (or both systems alternately: electric to start when there is no steam, and steam once the boiler has begun generating it).


COMMON MECHANICAL ATOMIZING NOZZLES
Atomization pressure varies depending on the fuel.
F.Oil
Heating Fuel Oil: 20 to 25 kg/cm² (284 to 355 PSI) - 120°C (248°F)
Heavy Fuel Oil: 21 to 29 kg/cm² (299 PSI to 412 PSI) - 135°C (275°F)
NOZZLES:
Common and H.O. (Heavy-Oil)
Atomization angles: 30°, 45°, 60°, 90°
Cone shape: as per brand designation
Outlet orifice
MECHANICAL ATOMIZATION WITH FUEL RETURN REGULATION
Atomization Tablet
Fuel Pressure: 20 to 30 kg/cm² (284 to 424 PSI)
Variable Return Pressure: 5 to 15 kg/cm² (71 to 213 PSI)
Turbulence Chamber
Fuel Oil Heating: 120°C (248°F)
Heavy Fuel Oil: 135°C (275°F)

Thus, for heavy fuel oil, we will see that to move it with pumps (generally of the positive displacement gear type), it is necessary to heat it to 60°C to achieve pumping without stressing the pipes and pumps (reducing its viscosity), and that to use it in the different burners, we will have to heat it to:

- For mechanical atomization, to more than 120°C (248°F), and even more in modern direct-start spark burners, around 145°C (293°F);

- In air atomization burners, it will also be heated to these temperatures (since air does not add heat when atomizing it, but rather cools it);

- In steam atomization burners, it will be heated to at least 85°C (185°F) (since steam adds heat, but it can be preheated to 110°C (230°F)). -and those with a rotary cup at least 85°C (185°F) and not much higher (since if it gets too hot it will "slide" on the cup, preventing it from being "sprayed" in droplets).

Heating F.Oil should be heated less because it has a lower "viscosity" than heavy F.Oil at the same temperature, around 120°C (248°F).

* Viscosity: is a measure that allows you to compare the work required to make a liquid flow or pass through a pipe or restriction. Generally, liquids decrease in viscosity at higher temperatures. There are several ways to express it numerically; generally, it is the time it takes for a certain quantity of liquid at a given temperature to pass through an orifice.

All fuel heated in tanks produces gases that are explosive or highly flammable; therefore, an appropriate heating system must be in place (with gas venting that discharges to non-contaminating or confined areas).

Excessive temperature causes fouling in the lines and vapor "plugs" that hinder pumping (loss of pump suction). Similarly, the presence of water causes atomization and combustion problems.

Regardless of the fuel used: before ignition, a purge with air (using maximum air pressure, for a time that depends on the type of fuel) must be performed to remove the mixture of combustible gases that may form in the combustion chamber (remnants of fuel that volatilize). Ignition can be violent due to the mixture of these gases and the insufficient air available for ignition, producing a combustion chamber explosion, which, depending on the type of boiler, can be highly dangerous.

Every boiler must be "ventilated or purged with air" before lighting its burners or fires, and every time ignition is attempted, even if the first attempt fails.

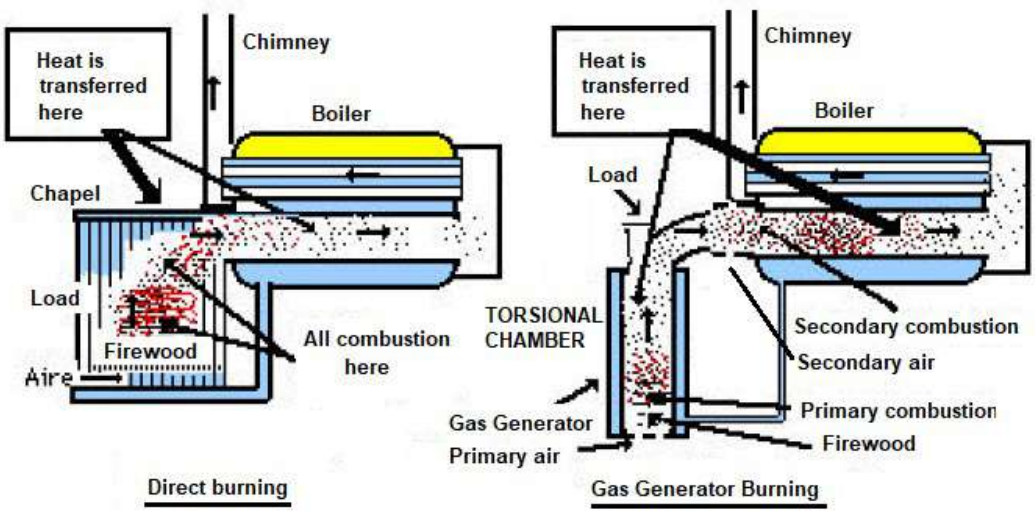
We will see that automatic burners will have this step included in their starting system.

In many situations, an auxiliary fuel will be necessary to ignite the main fuel: this could be a small gas burner (usually automatic), a manual gas burner, or a kerosene or diesel fuel wick.

In the case of wood, a small fire can be started with rags soaked in medium-weight fuel (with the firebox cool and ventilated).

All these operations must be carefully planned to avoid an accident (the auxiliary flame should be lit after purging with air and always before the main fuel).

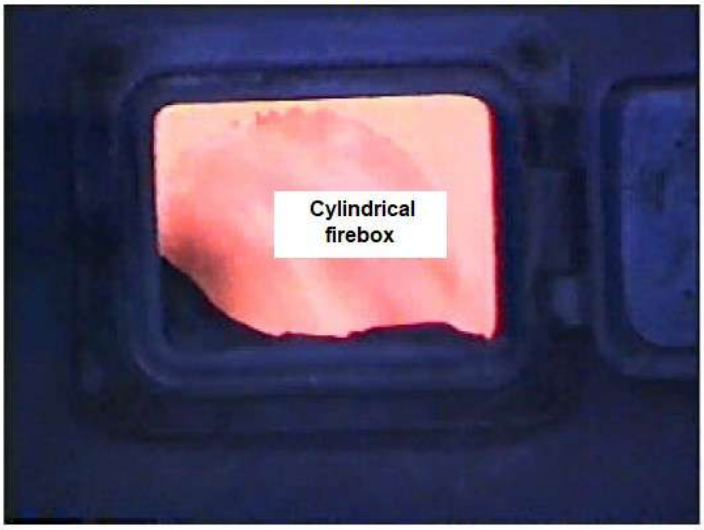
Do not attempt to ignite using the heat from the firebox refractory material; if there is no pilot light, there is a risk of explosion.



Wood combustion systems can be summarized in the following classifications: direct combustion and gas generator (torsional chamber).

In direct combustion, as the name suggests, combustion occurs completely within a combustion chamber, using high-temperature direct radiation. This allows for the combustion of virtually all imaginable fuels (wood and husks – rice, sunflower, nuts, etc., of all sizes: from small to large: from wood chips to long logs).

WOOD BURNING (EUCALYPTUS)
DIRECT FLAME VIEWED THROUGH THE PEEPHOLE



The combustion chamber where complete combustion takes place is generally a water-cooled structure (water-tube – called a "chapel" due to its shape). Its vaporization rate is very high compared to the boiler body itself (over 40%), giving the boiler excellent efficiency.

In gasifier combustion, partial combustion (gasification) occurs in a combustion chamber with insufficient air (producing a large amount of CO; this first chamber is cooled by water from the same boiler). A second combustion then takes place in another chamber (generally inside the boiler or main combustion chamber—primarily using convective and conductive heat, as the flame is less luminous).

The fuel typically tolerates large wood chips or short logs; not all fuels can be burned indiscriminately (it is less tolerant of high moisture content).

In gasifier combustion, only a minimal portion of the combustion occurs, resulting in very low heat production (as we saw, CO formation is only 1/3 of the total heat that carbon can produce). Heat transfer is low in gasifier combustion, occurring primarily in the boiler's combustion chamber (i.e., during the second combustion, making it crucial that this combustion is complete before the fuel enters the tubes).

Both systems maintain a fuel charge level, and their combustion is regulated by adjusting the primary, secondary, and other air valves.

If combustion needs to be stopped momentarily, the air valves will be completely closed.

However, caution must be exercised when restarting combustion in the case of the gas generator, which will require a pilot light (in some cases) because the secondary combustion needs to be reignited (otherwise, backfires may occur). In other systems, the primary flame is extended.

Combustion is controlled through the rear sight glass by regulating the air intake through the torsional chamber.

A bluish, short flame should be visible, ideally with automatic oxygen control via a zirconium oxide cell.

Undesirable elements in fuels:

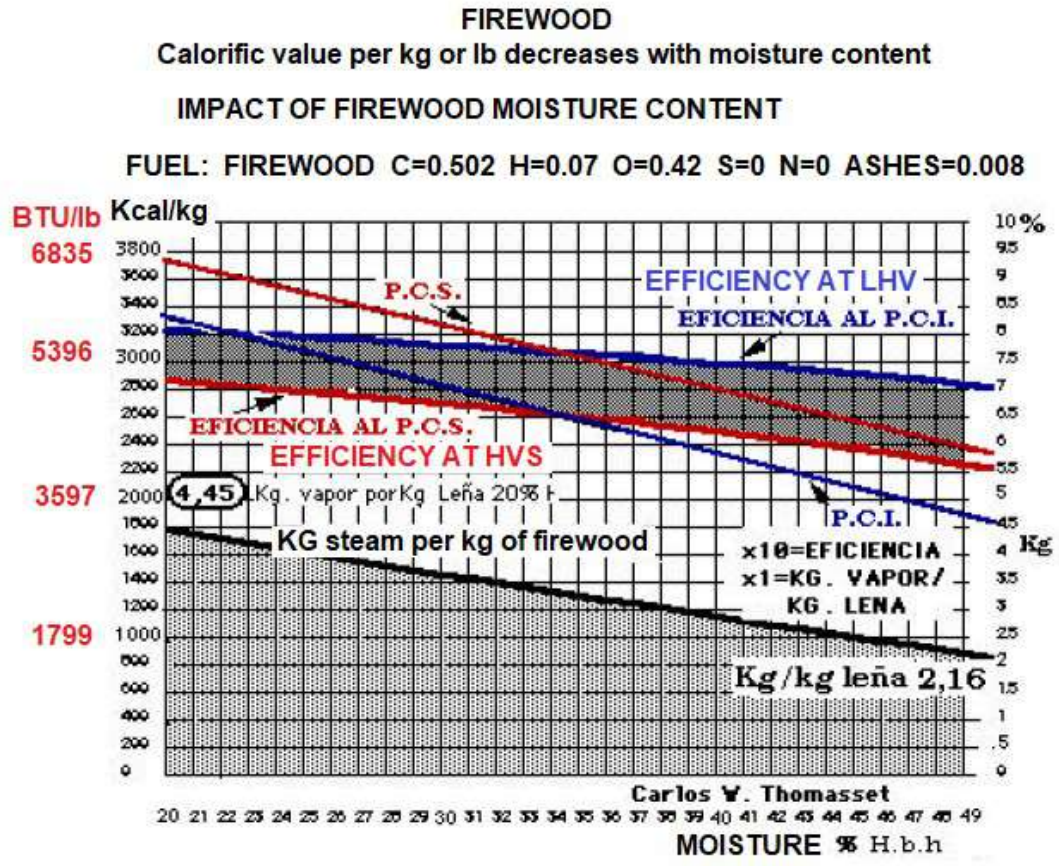
Any elements that could impair burner performance or combustion should be avoided.

Water in liquid and gaseous fuels, or "moisture in solid fuels," must be removed before reaching the burner. In the case of firewood, it should be as dry as possible, as these not only cause energy losses but can also lead to poor atomization in liquid and gas burners (even causing the burner to shut off or making it difficult to light).

Although a very small amount of water in the fuel can promote combustion—less than 1% in a complete emulsion—it is said to act as a catalyst.

In the case of firewood (eucalyptus and other biomass), the presence of excess water not only causes losses through evaporation, but also makes combustion more difficult to complete. This leads to premature fouling of the boiler's heat transfer surfaces, resulting not only in heat loss through the chimney but also in hindering the passage of gases. This, in turn, causes a lack of draft (the excess air is drawn down when, under these circumstances, the high humidity necessitates working with more excess air).

Although no smoke is visible from the chimney, there is a significant loss of unburned gases. These gases not only contribute to ash accumulation on the tube surfaces but are also pollutants (not only CO, but also a variety of other undesirable organic compounds, representing unused heat that contaminates the atmosphere).



Sulfur contributes very little heat and is highly corrosive; it should be avoided whenever possible (its corrosion can be very significant in the boiler, occurring in cold areas such as heat recovery units, economizers, and air heaters, or in hot areas such as superheaters—in this case, it acts due to the vanadium naturally present in fuel oil).

This sulfur, combined with the moisture in the fuel plus the water produced when burning the hydrogen in the fuel, forms sulfur dioxide (which, when catalyzed, forms sulfuric acid, a highly corrosive element when operating below the dew point of the gases, approximately 180°C (356°F) for fuel oil).

This corrosion causes significant damage to economizers, air heaters, and certain cold parts of the boiler. Fuel oil, coal, and rice husks contain sulfur in varying proportions.

EXTERNAL CORROSION PROBLEMS
Extensive corrosion near refractory materials and internal perforations are already present.

However, while sulfur appears to be the major corrosion problem in the combustion chamber of boilers (especially in cold areas, under refractory linings, etc.), cellulosic fuels (firewood) and gases can also be corrosive when combustion is incomplete.

Firewood with high moisture content or gases (natural gas, bottled gas, etc.) with incomplete combustion (lack of air, low combustion temperature, poor air-fuel mixture, etc.) result in acidic combustion (due to organic compounds), such as pyroligneous acids, which

attack the metal in cold areas: under refractory linings, smoke boxes, echo chambers, air heaters, etc. This often surpasses the corrosive effect of sulfur, which we tend to be more careful about.

Some boilers have lost metal thickness on the flue gas side within just a few years, rendering them unusable due to the thinning of the tube walls. Sludge and sand in liquid fuels cause wear and contamination problems.

Installing filters and ensuring the fuel inlets are properly located allows for cleaning (settling tanks for water and sludge that are regularly drained). In gases, if they are not properly treated, sulfur compounds, carryover deposits, and even soot can occur (something no one imagines, but soot is produced if there is insufficient air, poor gas-air mixing, low temperature, etc.).

Fuel Handling:

Gaseous fuels are very dangerous, and their handling is subject to very strict regulations.

All handling of liquid fuels must be done according to their "hazard," that is, whether they are easily "flammable" (explosive when mixed with air or easily ignitable; this is measured by the **"Flash Point"** test: the temperature at which they ignite in air upon contact with a flame) or whether they can easily sustain combustion (this is measured by the **"Fire Point"** test: the temperature at which the fuel, once ignited, is capable of continuously burning on its own in contact with air).

Thus, we will see that the order of care in handling them is from Gas Oil to Diesel Oil, then Heating Oil, and finally Heavy Fuel Oil (taking care never to put gasoline or solvents in a tank containing fuel).

In the case of firewood, if "piles" or "heaps" of finely chopped wood ("chips") are established, when accumulated with moisture, if it is left for a long time it can cause "burning" or combustion by fermentation, which, although it is a slow combustion at first, can degenerate into a fire.

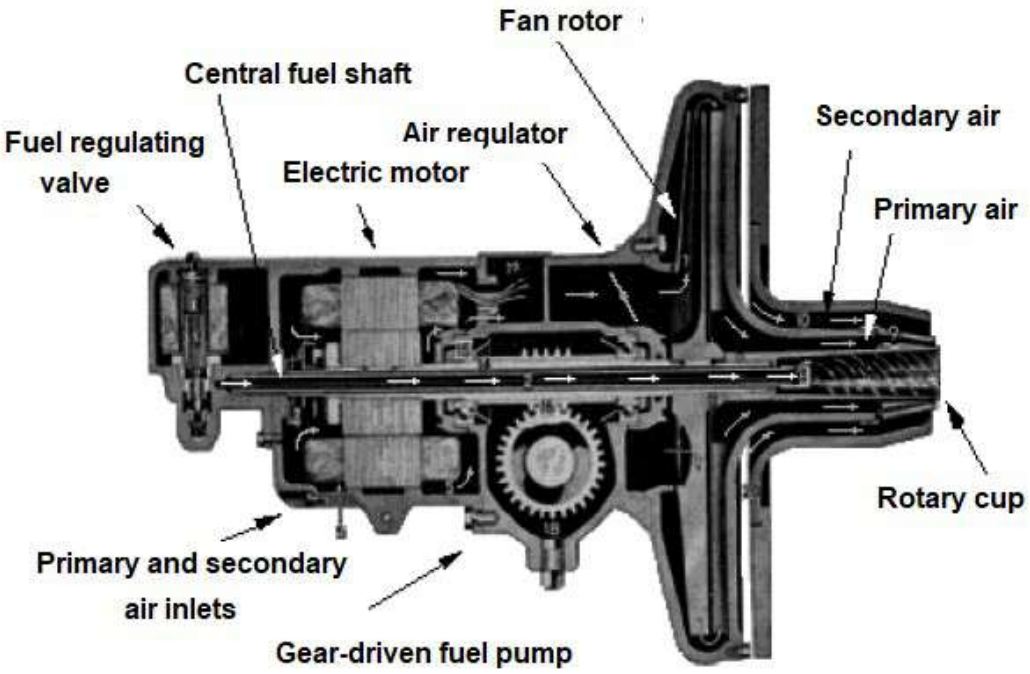
Whenever entering fuel tanks or homes, these must be properly ventilated to ensure there are no explosive mixtures of vaporized fuels with air.

If it is necessary to weld or repair a tank that has previously contained fuel, a 48-hour steam cleaning or washing process must be carried out (introducing low-pressure steam through a pipe to distribute it inside, ventilating with air, and draining the condensate from the bottom; then circulating air with a fan).

Before starting to weld, test, if possible, with an explosimeter to ensure there is no mixture of explosive gases. It is also advisable to maintain strong air circulation while welding or repairing the tank, as gases may be released when the tank's metal sheet heats up during the welding process.

Never attempt this type of work alone. Take all necessary precautions: it is a very dangerous task.

Fuel tanks must be properly designed to facilitate gas venting, annual cleaning, water purging, fuel heating, external corrosion, flooding from rain or fuel losses to the subsoil, as well as their insulation against the rigors of cold winter.



ROTARY CUP BURNER FOR LIQUID FUELS

Remember that: each burner is designed for a specific type of fuel, so you should take care to avoid mistakes when ordering fuels or be careful when mixing different fuels, as this can cause combustion problems or failures that can be significant.

The use of dual-fuel burners (liquid and gaseous fuels) requires a series of precautions, especially when switching from burning liquid fuel to gaseous fuels. This is because liquid fuels can leave behind vaporized fuel residues (which can create ignition points for the gas outside the normal flame zone, prevent the residual flame sensor from detecting them and blocking the main gas ignition, or obstruct vital areas for the combustion gas intake, preventing ignition in the appropriate area of the burner base).

steam production capacity of 15 tons/hr, 12 kg/cm², 170 PSI

This has led to very serious accidents. The most important thing in these cases is to pre-establish the checks and procedures for changing fuels, and to take the necessary time to complete them, since an unprepared maneuver without prior checks can result in an accident.

These accidents usually occur in the smoke boxes, in the detachment of the burner (hearth explosions), which affect the people who are observing the maneuver: always stand to the side when proceeding to light the burner, taking care that the covers are not in the area where you are standing if they open.

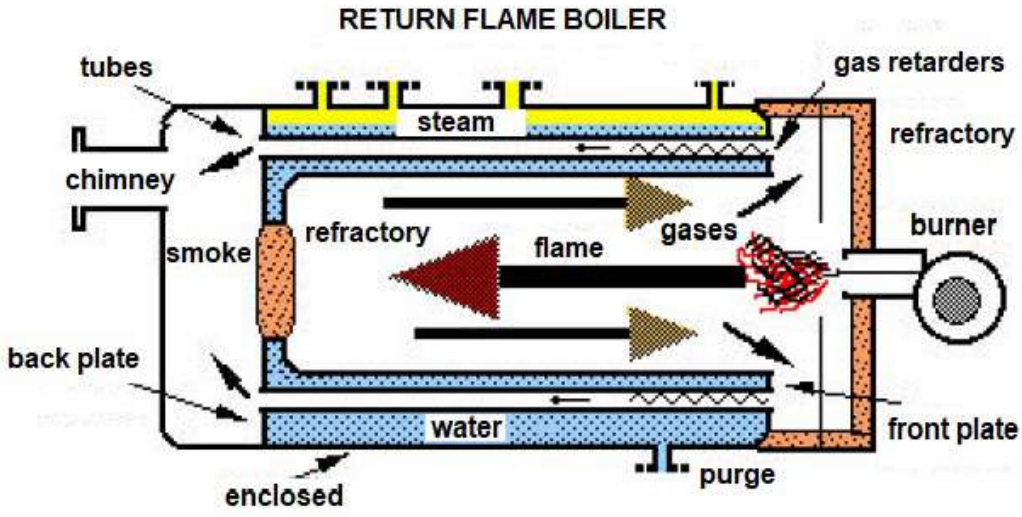
CHAPTER 4: Components of a Boiler Part 1

Structure (body and tubes)

Boilers are composed of a metal structure, usually cylindrical, made of iron. This pressure vessel is partially filled with water (or a mixture of water and steam) and partially with steam (steam chamber).

Another part is generally made up of tubes (in which the water-steam or combustion gases circulate), depending on the type of boiler (water-tube or fire-tube).

In fire-tube boilers, the body or casing has "plates" at each end that support the combustion chamber (which can be smooth or corrugated as needed) and the "flue tubes" (which are either "mandrelled" or “mandrel and welded” to the plates, depending on the standards).



Mandrilling:

This is the expansion of the tube over the hole in the plate. It is done with a tool that has a series of steel rollers that open as they rotate due to the action of the central shaft, stretching the tube and increasing its diameter to a desired value of material deformation once the diameters are equalized.

Depending on the material, this deformation will be: steel (iron) from 5% to 7%, stainless steel from 4% to 5%, and copper and its nickel alloys from 8% to 10%. See chapter later.

Then, in some cases, they may be "flared" (this is done on the protruding part of the tube above the plate to prevent the end of the tube from being "burned" by the hot gases, by "flaring" or "relieving" the protruding edge against the plate) or "belled" (a bell-shaped expansion of the protruding end of the tube above the plate to prevent displacement when necessary or to improve the circulation of gases or water).

In fire-tube boilers, or in water-tube boilers, this is done with a mandrel or percussion cone. A combination of mandrelling (expansion of the tube into the hole in the plate) and sealing with electric welding (followed by a second mandrelling to "relieve stress").

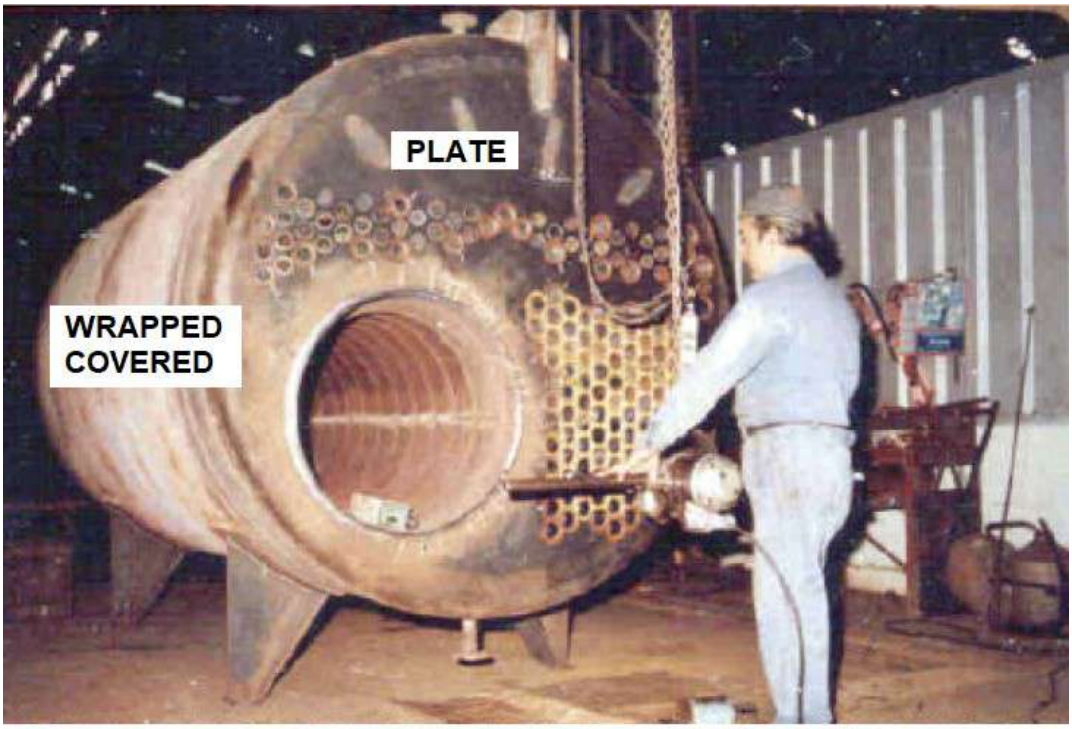
However, in water-tube boilers, the tubes are generally only mandrelled (except in the headers) in the domes. Typically, the tube is mandrel to a complete seal and a holding tension, with a "flaring" effect not only to prevent its "extraction" due to the stresses it withstands, but also to improve the circulation of the water entering the tube (a "funnel" effect, which reduces the "pressure loss" of the water as it enters the tube).

MANDRILLING TUBES IN A WATER-TUBE BOILER DOME

Today, in almost all fire-tube boilers, the tubes are mandrel-grooved and welded to the plate.

The tubes are welded to achieve a good seal, but some tubes are welded deeper than others, as these will be the "stay" or support tubes between the plates (meaning they withstand the pressure exerted on the flat plates).

Although the tubes are welded, they must first be mandrel-grooved and then, after welding, mandrel-grooved again to loosen the tension generated by the welding process and retighten the mandrel that loosened during welding (the tube that has reached a certain temperature). The mandrel acts as the "anchor" of the tube to the plate, and the weld provides the seal, especially in the case of the "stay" tubes.

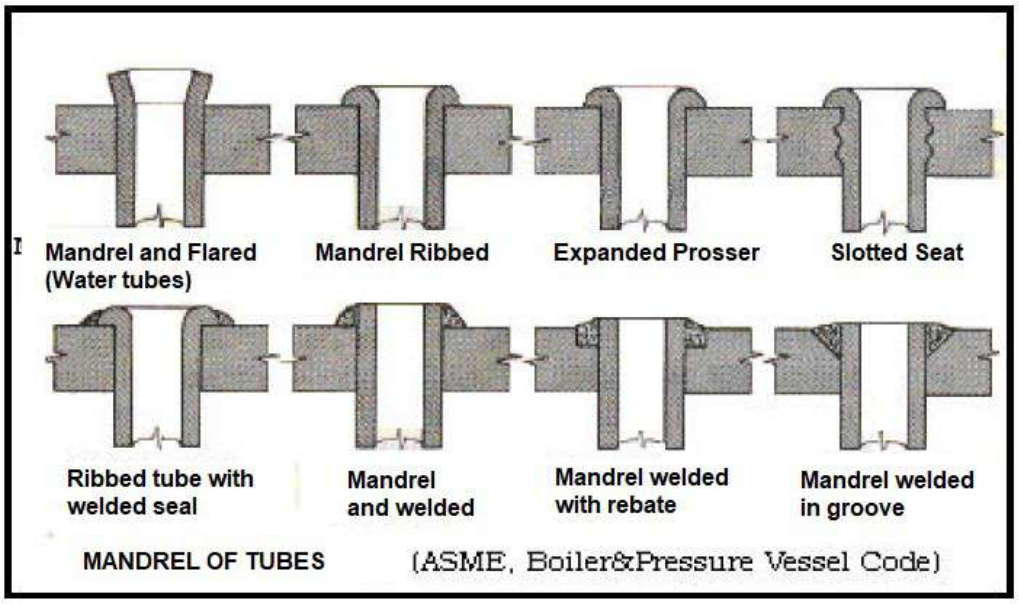


MANDRILLING BORING TUBES TO PLATES (HOMO-TUBULAR BOILERS)

Although the tubes are welded, they must first be mandrel-grooved and then retightened after welding to relieve the tension generated by the welding process and to retighten the mandrel that has loosened during welding (the tube that has reached a certain temperature).

The mandrel acts as the "anchor" of the tube to the plate, and the weld provides the seal, particularly in the case of the "stay" tubes (reinforced tubes whose function is to withstand this great stress and that of the boiler's own pressure which exerts a stress on the plates).

The mandrel is what anchors the tube to the plate, and the weld provides the seal. The welding also acts as an anchor (if the tubes were not mandrel-grooved, there will most likely be problems over time, from losses in the welds due to insufficient "anchoring" or corrosion in the gap between the plate and the tube).

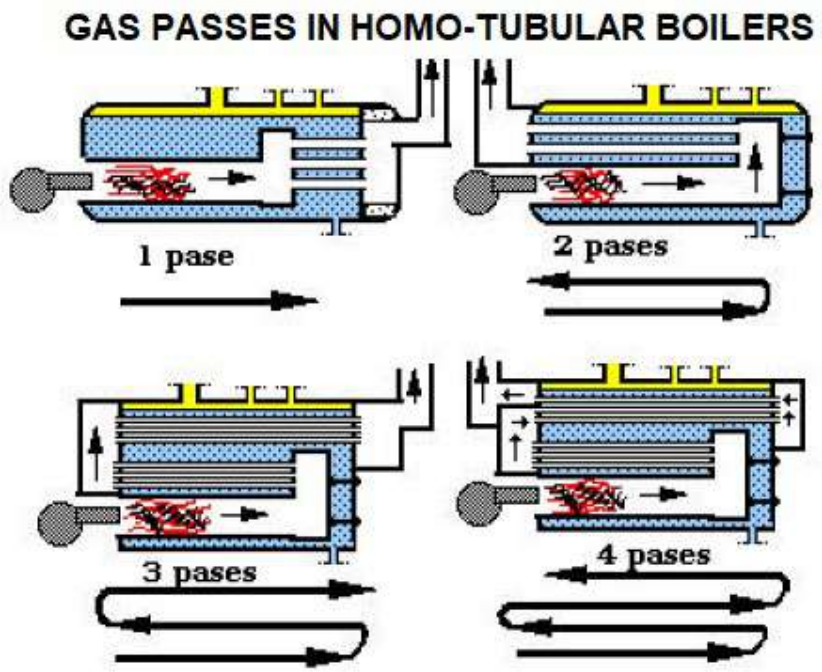


Since the pressure vessel of a boiler is constructed by welding, even though the material is generally low-carbon (and very high-purity) steel, it retains stresses in the welded area.

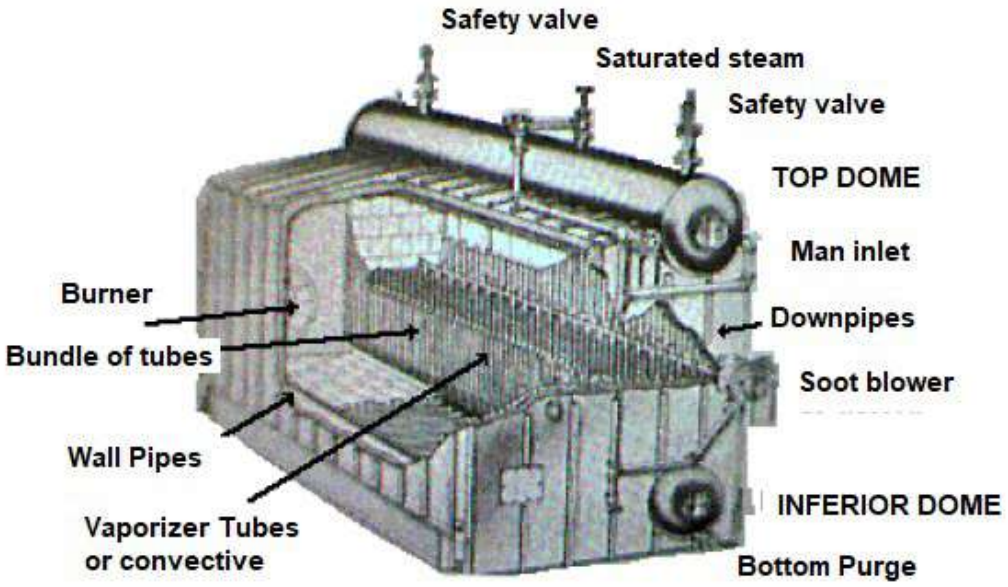
Therefore, it undergoes a "stress-relief" heat treatment. This treatment has a cost, but it is generally worthwhile, as it reduces the risk of failures due to cracks in the welded areas during the boiler's lifespan (which in Uruguay is generally more than 30 years).

HEAT TREATMENT FURNACE FOR STRESS RELIEF

Fire-tube boilers are often classified by the number of "passes" (or changes in the direction of gas flow). The "first pass" is the furnace tube (when present), and the "second pass" is the "first tube pass." Generally, boilers do not exceed four passes in total, with three-pass boilers being the most common, although smaller boilers are usually two-pass.



Water-tube boilers are made up of "domes" and/or collectors that will be joined by tubes through which the water circulates (which will be "mandrel-shaped" and if necessary "bell-shaped" or welded depending on whether it is a dome or a collector).



The metals that form these pressure structures are special (although they are generally not high-carbon steels, they are manufactured according to very strict standards – and should not be replaced by common materials, since they must withstand very significant stresses at generally high temperatures, tensions due to the aforementioned effects, and all types of exposure to a corrosive environment, whether from gases or water/steam).

The welds are also done with special electrodes, following specific standards (procedures), and by qualified welders.

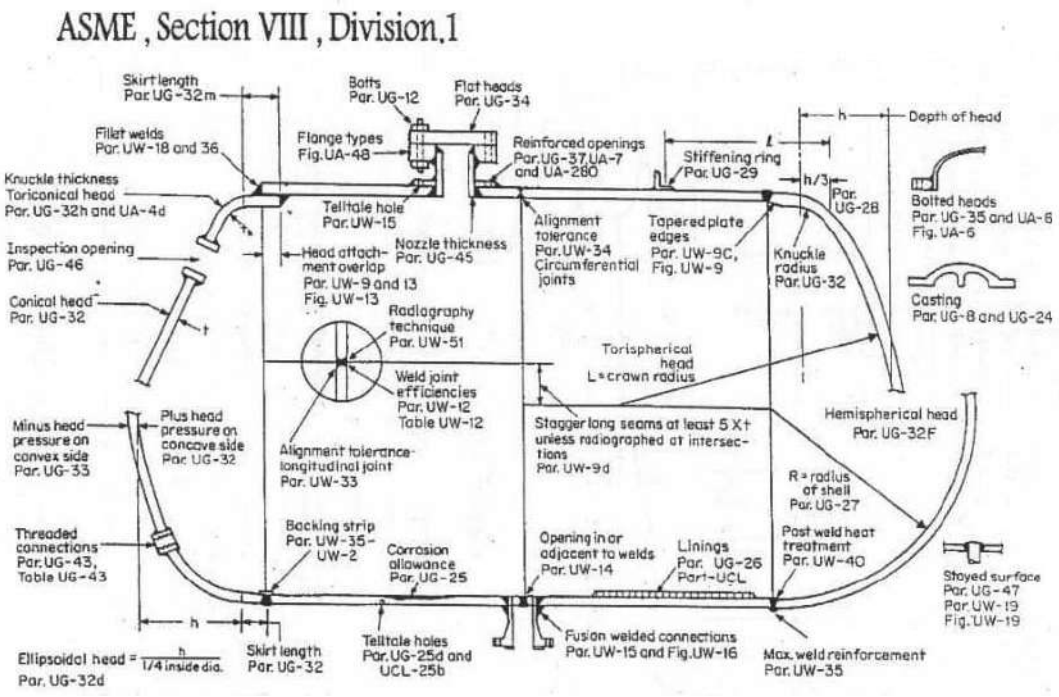
The "shells" and their "plates" in fire-tube boilers, and the "domes" and "collectors" in water-tube boilers, once manufactured, undergo annealing to relieve stress and are subjected to X-rays or other tests to inspect the welds or areas of risk (cracks, inclusions, etc.).

Once its construction is complete**, hydraulic tests** are performed to observe the behavior of the structure and the connection of the tubes to the plates, domes and collectors.

Note in the following figure that the construction standards for pressure vessels (represented in a simplified form by a specialist), especially boilers (vessels subjected to variable stress and temperatures), adhere to very strict "construction standards," as human life and the integrity of the environment in which a boiler is installed are at stake.

The joining of the "plates" to the "shells," and the welding of the "shell" upon itself (to close its circumference), are particularly "delicate" areas, as they are subjected to pressure stresses and, in the case of boilers, to the variable stress of expansion and contraction of the cylindrical combustion chamber (where combustion occurs from "all to nothing," with 20% to 40% of the total combustion heat being transferred to the water) and the stress of expansion and contraction of the tubes (which transfer a large part of the heat, between 40% and 60%, from "all to nothing").

This stress is transferred to the "plates" and this can "fatigue" the joint until it weakens (causing one of the most serious accidents, which is the "explosion" of the pressure body).


ASME , Section VIII , Division.1
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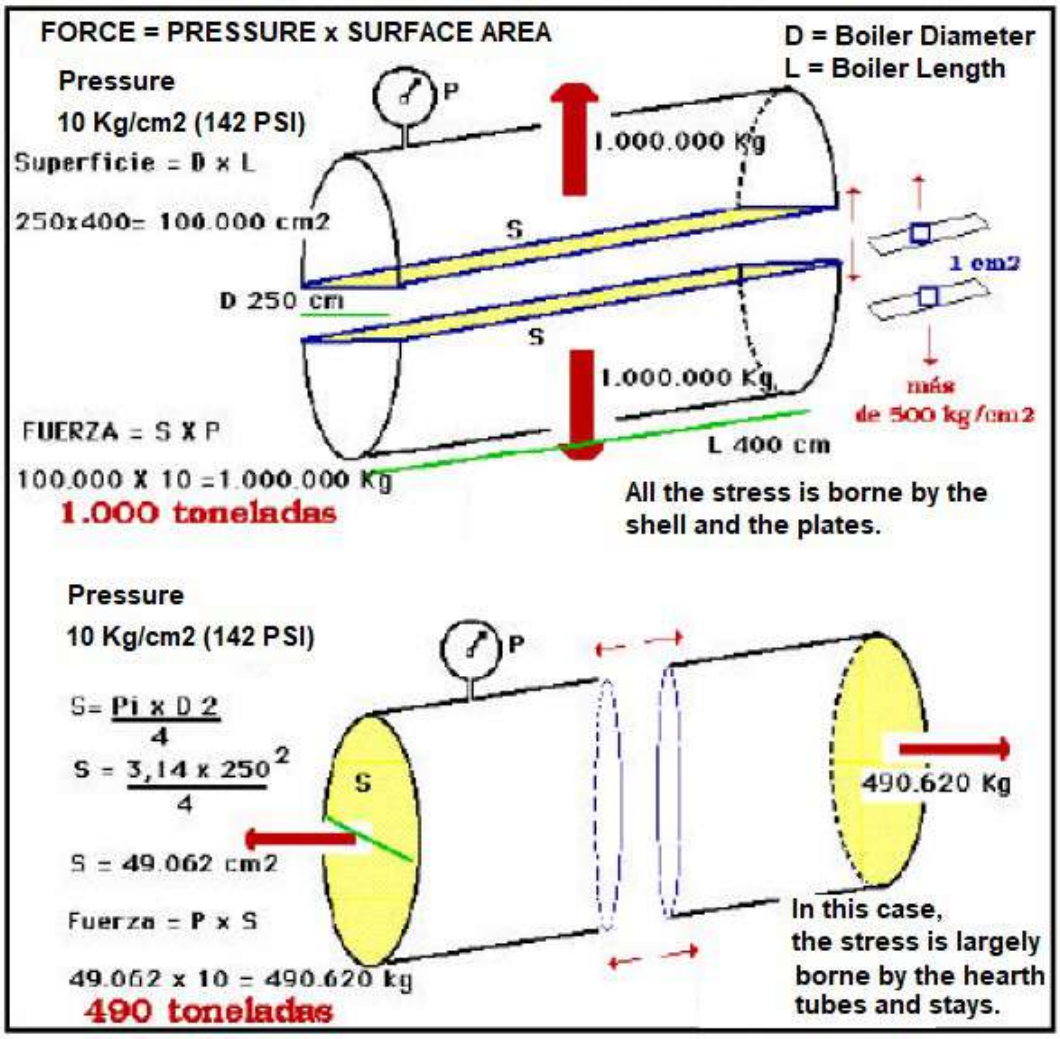
Backing strip Par. UW-35 - UW-2
Corrosion allowance Par. UG-25
Opening in or adjacent to welds Par. UW-14
Linings Par. UG-26 Part-UCL
Post weld heat treatment Par. UW-40
Stayed surface Par. UG-47 Par. UW-19 Fig. UW-19
h
Ellipsoidal head = h / 1/4 inside dia. Par. UG-32d
Skirt length Par. UG-32
Telltale holes Par. UG-25d and UCL-25b
Fusion welded connections Par. UW-15 and Fig. UW-16
Max. weld reinforcement Par. UW-35

Hydraulic testing:

This involves subjecting the boiler body to a pressurized water pressure at ambient temperature, after completely removing the air from the interior. It is an internal stress within the material's elastic limit (for a specific time) to observe any leaks or deformation.

The test pressure varies according to standards: generally, for medium-pressure boilers, it is set at one and a half times the design pressure.

Hydraulic testing must be carried out by qualified personnel (professionals or qualified individuals). Exceeding the pressure, time, or proper procedure risks damaging the boiler.



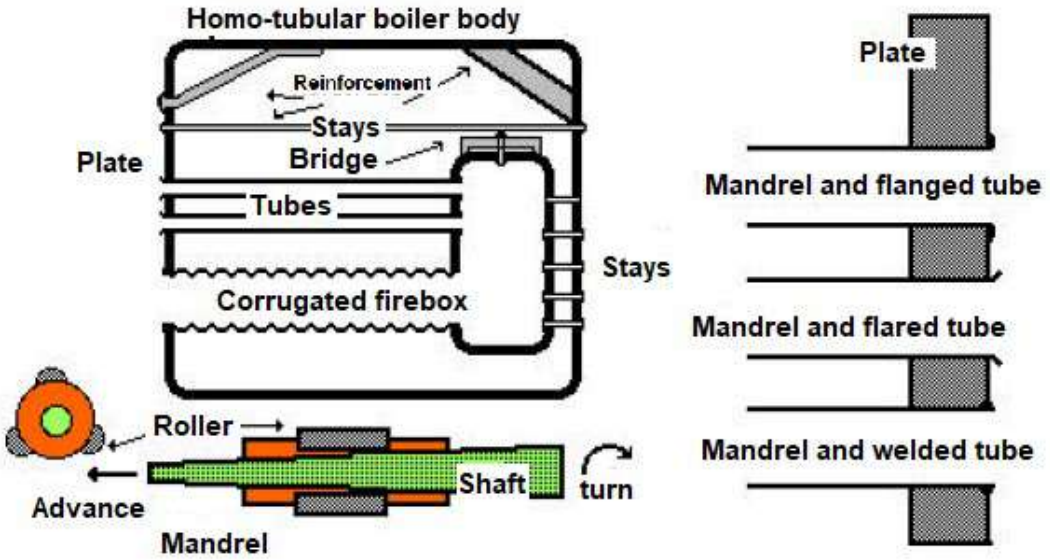
Fire-tube boilers may also have stays (internal braces) or other elements (braces) and stay tubes (tubes that may be thicker, welded or mandrel-grooved, flanged, or flared more firmly to the plates).

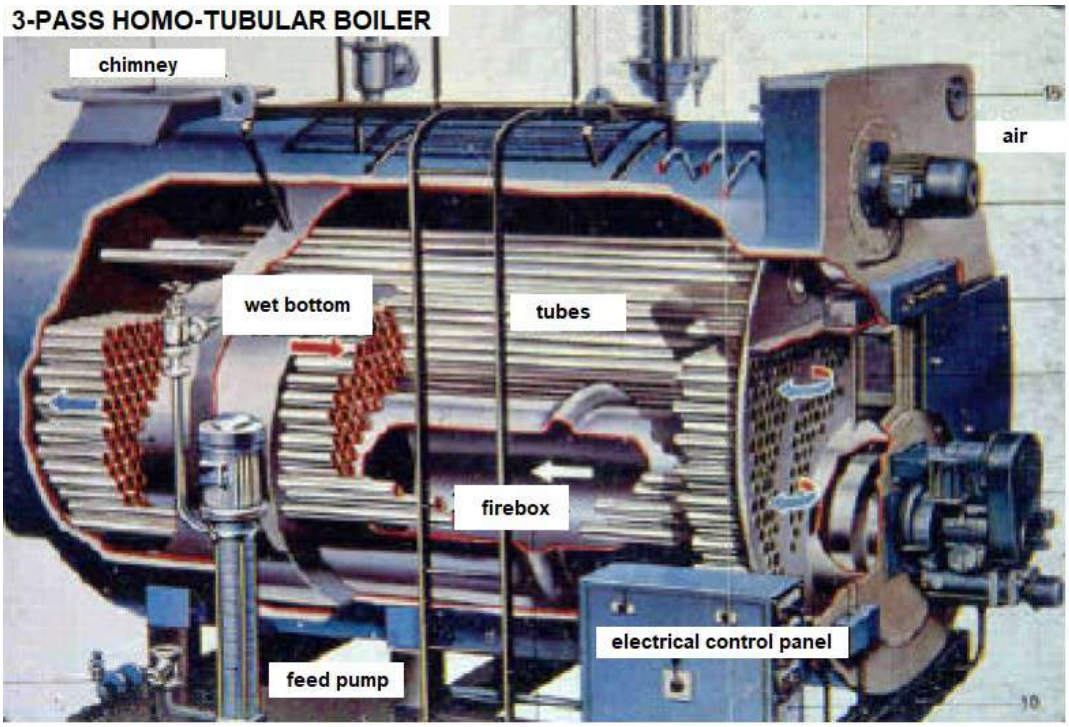
These elements keep the plates or flat areas correctly aligned (without deformation) when subjected to the high stresses caused by pressure.

For a simple boiler operating at 7 kg/cm² (99.5 PSI) gauge pressure, with plate diameters of Ø1400 mm (55.1 in), the force the plate must withstand will be the product of the surface area and the pressure in compatible units: 108 tons (from which the stress on the surface area occupied by the combustion chamber and the tubes on the plate must be subtracted).

These components must be treated with great care, as their good condition is essential (do not modify them, protect them from any type of corrosion, inspect them periodically, etc.).

The stress on the casing is even greater.





The cylindrical combustion chamber of fire-tube boilers can be "corrugated" (with cylindrical shapes of varying dimensions and profiles, which allows the chamber to better withstand pressure and partially absorb the significant expansion stress caused by the high temperature of the flame inside)

or "smooth" (a simple cylinder, which may have cylindrical supports, such as rings, on the water side, i.e., the cooled side).

Smooth cylindrical combustion chambers are limited to small-capacity boilers, since the problem of expansion is not taken into account, although in some cases a single "ruffle" or "expansion joint" is added for this purpose.

The most common "corrugated" system is the FOX system (since it is the simplest to manufacture). Typically, once the firebox has been rolled with a single longitudinal weld, it is then subjected to a type of lathe with embossing wheels that create the "crisp" shape, and torches that heat the material in the area to be deformed.

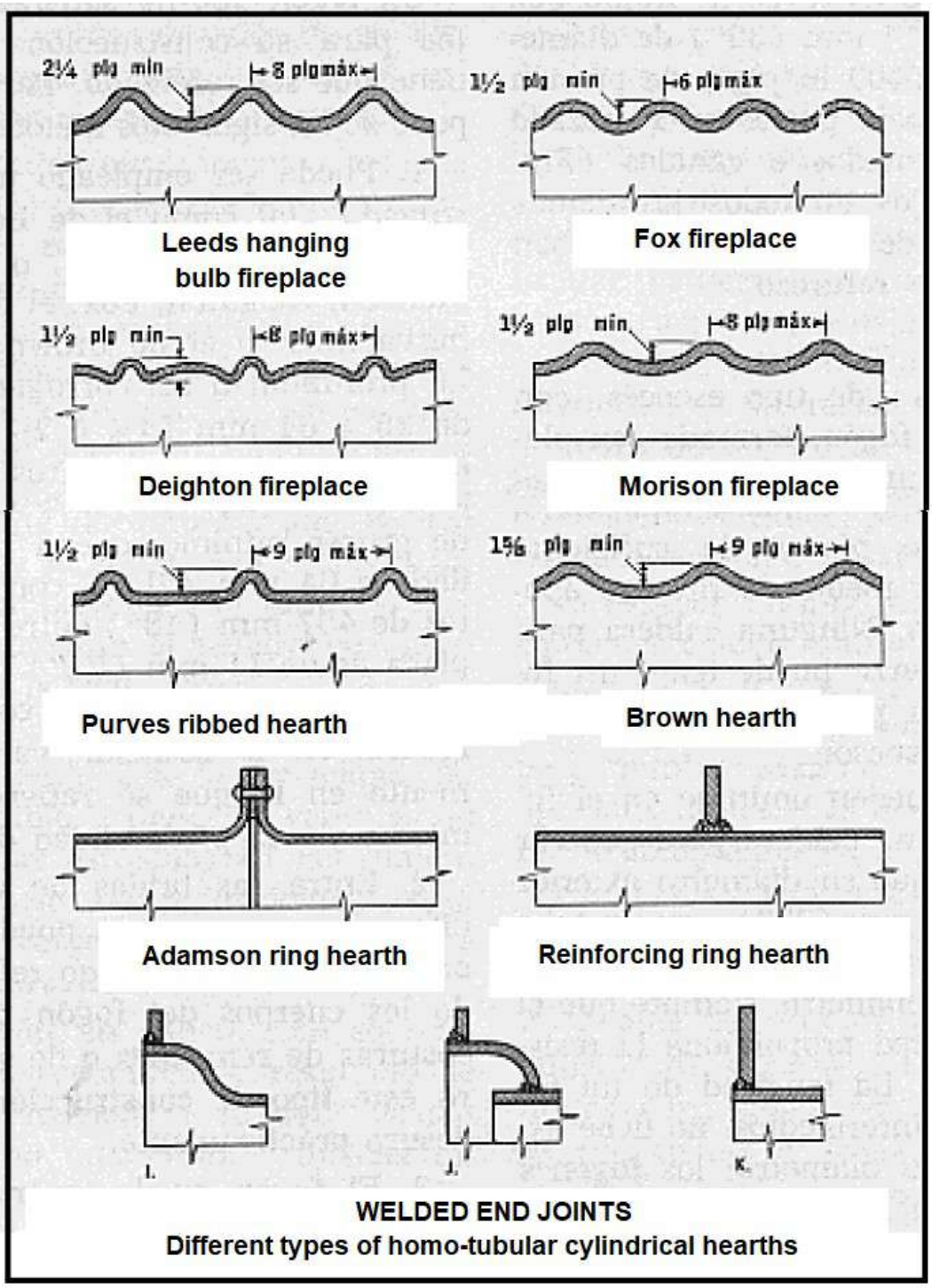
CONSTRUCTION OF A CYLINDRICAL HOMO-TUBULAR BOILER

Another way to make a "corrugated" firebox is to create it in two halves using a press, after preheating the material to be deformed, and then welding the two halves together.

The cylindrical combustion chamber of fire-tube boilers serves the dual purpose of enabling combustion and operating at high temperatures. Therefore, adequate water cooling is essential. This cooling circulation can be affected not only by a low boiler level but also by various water surface conditions (chemical limits and contaminants), as well as the combustion percentage and flame configuration.

However, it also plays a crucial role in creating a water "pump" within the fire-tube body. This not only cools the metal of the combustion tube but also "washes" the fire-tubes, preventing sludge buildup.

Boilers without combustion tubes experience problems if the combustion process produces sludge, which is not easily removed through the purge system.


2¼ plg min
8 plg max
Leeds hanging bulb fireplace
1½ plg min
6 plg max
Fox fireplace
1½ plg min
8 plg max
Deighton fireplace
1½ plg min
8 plg max
Morison fireplace
1½ plg min
9 plg max
Purves ribbed hearth
1⅝ plg min
9 plg max
Brown hearth
Adamson ring hearth
Reinforcing ring hearth
I.
J.
K.
WELDED END JOINTS
Different types of homo-tubular cylindrical hearths

The expansion of the cylindrical combustion chamber in a fire-tube boiler causes stress between the plates (unless the combustion chamber is "floating," as in some "return flame" boilers).

The tubes connecting the plates and the shell withstand this stress, since the heating of the combustion chamber at certain times causes greater expansion than the tube passages.

Therefore, there are reinforced tubes, "stays," whose function is to withstand this significant expansion stress and the pressure exerted by the boiler's steam itself, which acts on the plates. These plates are flat, and therefore their shape is not ideally suited to withstand stress that could distort them.

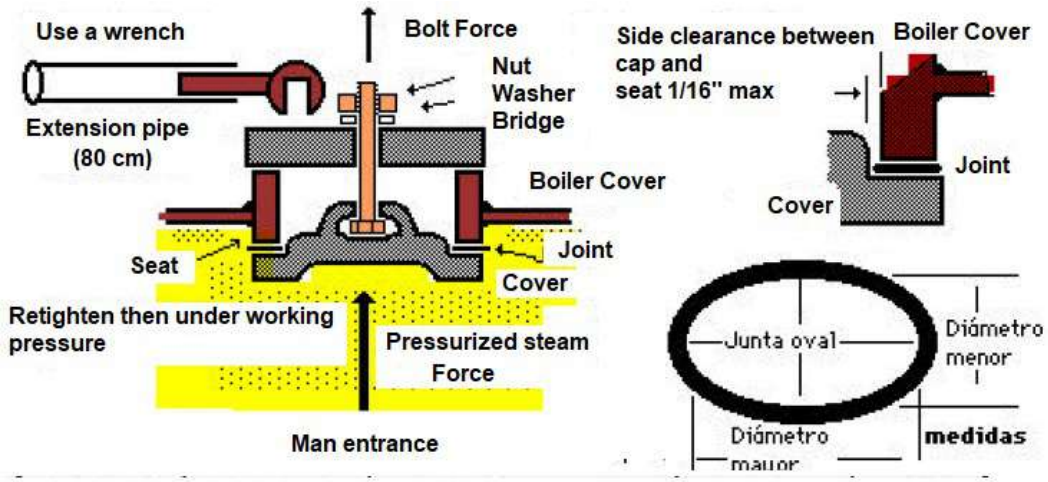
Today, tubes are mandrel-grooved and welded; previously, they were only mandrel-grooved and upset (that is, their ends were flattened or flared for two reasons: to better withstand stress and to prevent the protruding ends of the tubes from burning during the first pass, where the temperature reaches 900°C (1652°F) at the furnace outlet).

Stay tubes, which used to be thicker and sometimes secured with nuts, are now generally welded with a stronger weld, a deeper weld, than tubes that only need to maintain a watertight seal with the weld alone.

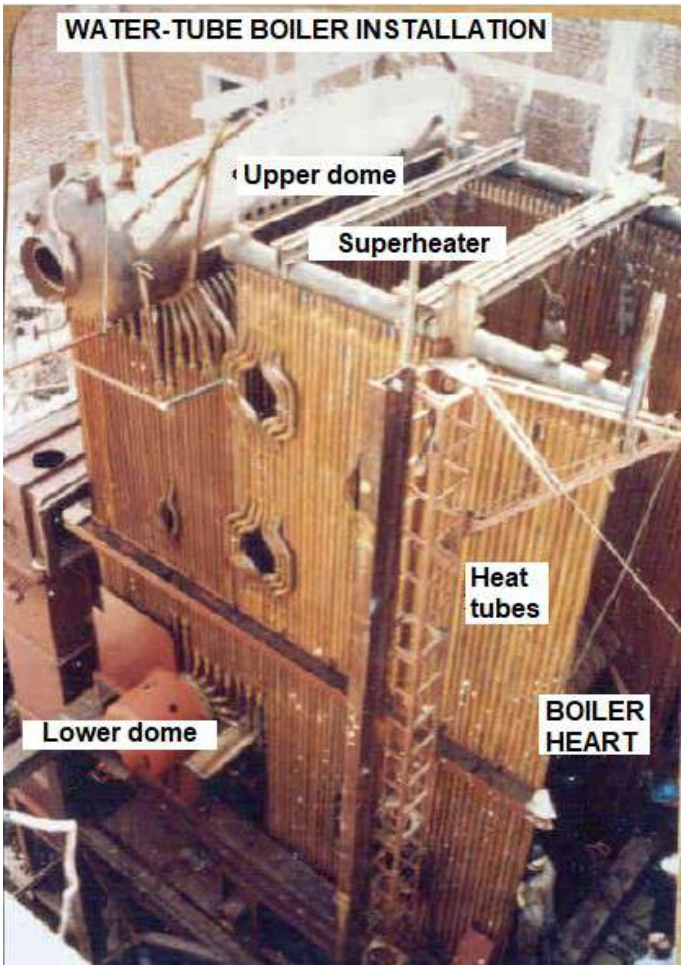
When a boiler is scaled, the combustion chambers, plates, and tubes experience reduced cooling, leading to increased expansion that tends to crack the mandrel welds, loosen the mandrel tubes, crack the tubes and plates between tube holes, or even cause cracking at the combustion chamber ends, or, in some cases, fatigue and collapse.

This same problem of abnormal expansion occurs when boilers are heated too quickly from a cold state.

The manholes, also known as "head" or "hand" access points, allow us to inspect the inside of the boiler for cleaning and general observation.

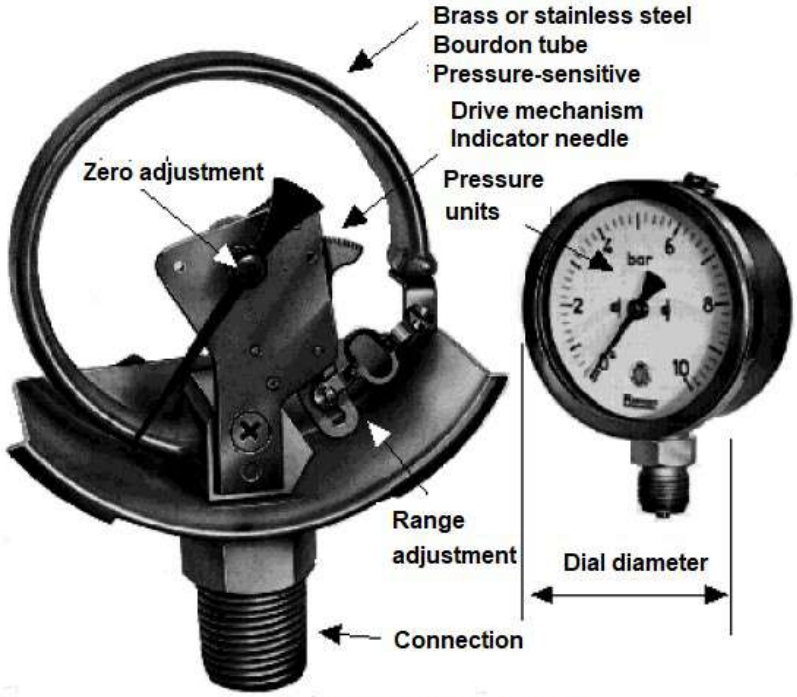


To this "body" that forms the boiler, we must apply a series of accessories for its correct operation and safety, which we will discuss below.



The pressure gauge

This component allows us to monitor the internal pressure of the water and steam (working pressure). It is crucial that its reading is accurate, as the stress the boiler endures is measured based on pressure, and the quality of the steam is controlled by pressure (as we saw, the saturation temperature of water vapor corresponds to a specific pressure). We can say that it is the most precise instrument required in the boiler.



BOILER PRESSURE GAUGE

A needle indicates the pressure in established units (kg/cm², bar, PSI, lb/in², etc.). The reading can be absolute or relative, but it is generally relative: "gauge." This is verified by exposing the connection to air—or by cooling the boiler with the atmospheric valve open; the pressure will read zero, as it is gauge pressure.

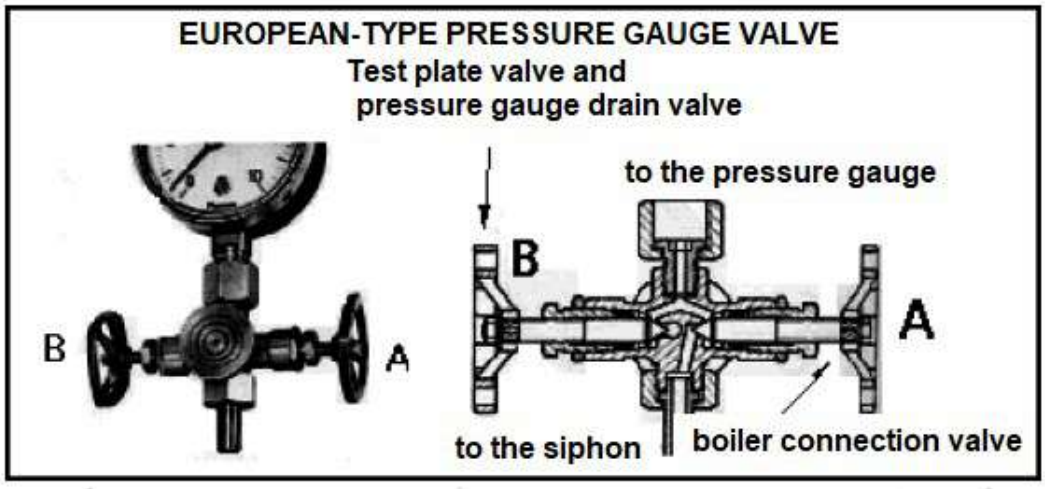
The needle is generally moved by a bent metal tube (bronze or stainless steel) called a "Bourdon tube," which, when subjected to pressure, tends to straighten, moving a mechanism of levers and gears that rotate the needle.

The pressure gauge scale should be 11/2 times (more than five) the "ringing" pressure (that is, the maximum design working pressure for the last safety valve to open), and its dial should be large enough to be seen from anywhere in the boiler room (and equally well illuminated).

The pressure gauge will be connected to the steam chamber with a 3-way valve for eventual purging or the connection of a master pressure gauge or changing the pressure gauge (there are generally two types of valves, American type or European type; the American type has a 3-way valve, the European type has 2 valves that perform the same function), in addition to a system that isolates it from the direct action of the steam (heat and corrosive gases), which may be: a "pig's tail", a 'U' tube or chamber.

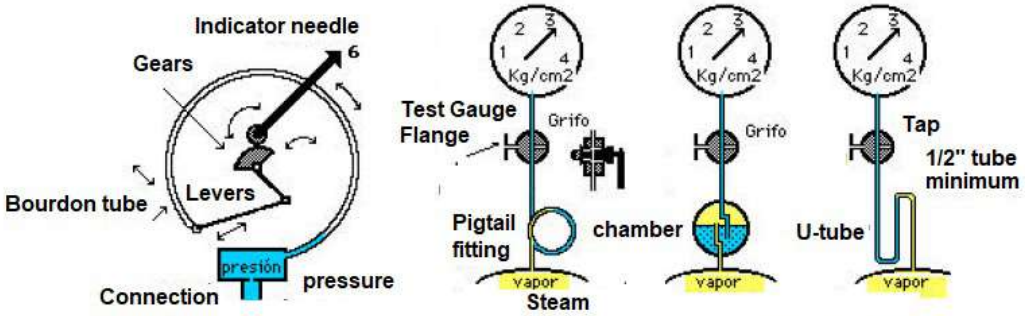
The 3-way valve is special; the pressure gauge and the outlet to the standard (plate) can never be isolated, so that the pressure gauge remains with hydraulic pressure, in a false pressure, since the internal pressure will go through the hole in the plate, or steam will escape through the plate; The handle will move downwards along the pipe (minimum 1/2" pipe) when in normal operation. This way, it will never be accidentally disconnected and the internal pressure will be ignored.

If the connection to the boiler is closed, the pressure will drop to zero due to the discharge through the plate, or the master pressure gauge can be used while the service pressure gauge is being replaced.



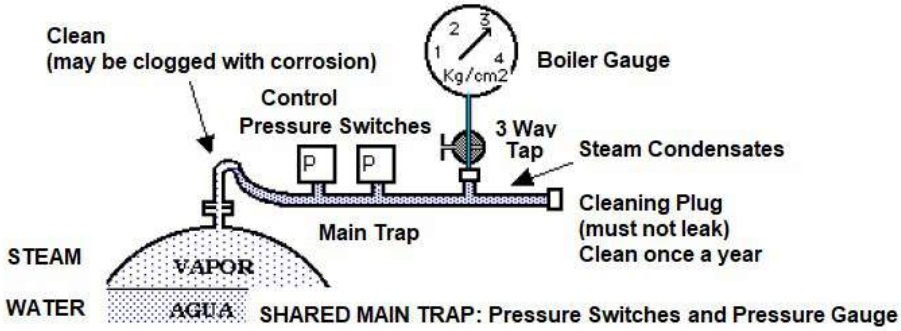
In European-type taps, the pressure gauge and the plate of the test master pressure gauge are already separated by a valve that closes the connection to the plate. This makes it possible to become isolated from the boiler accidentally if someone closes the valve connecting to the siphon.

Pay close attention to the operation of these valves to avoid an error that simulates a false pressure reading (tap closed to the siphon connection). If the pressure gauge is closed, the plate also closes, so the pressure gauge cannot be changed while the master gauge is in service.



Manometer mechanism

Manometer connection instructions



SHARED MAIN TRAP: Pressure Switches and Pressure Gauge

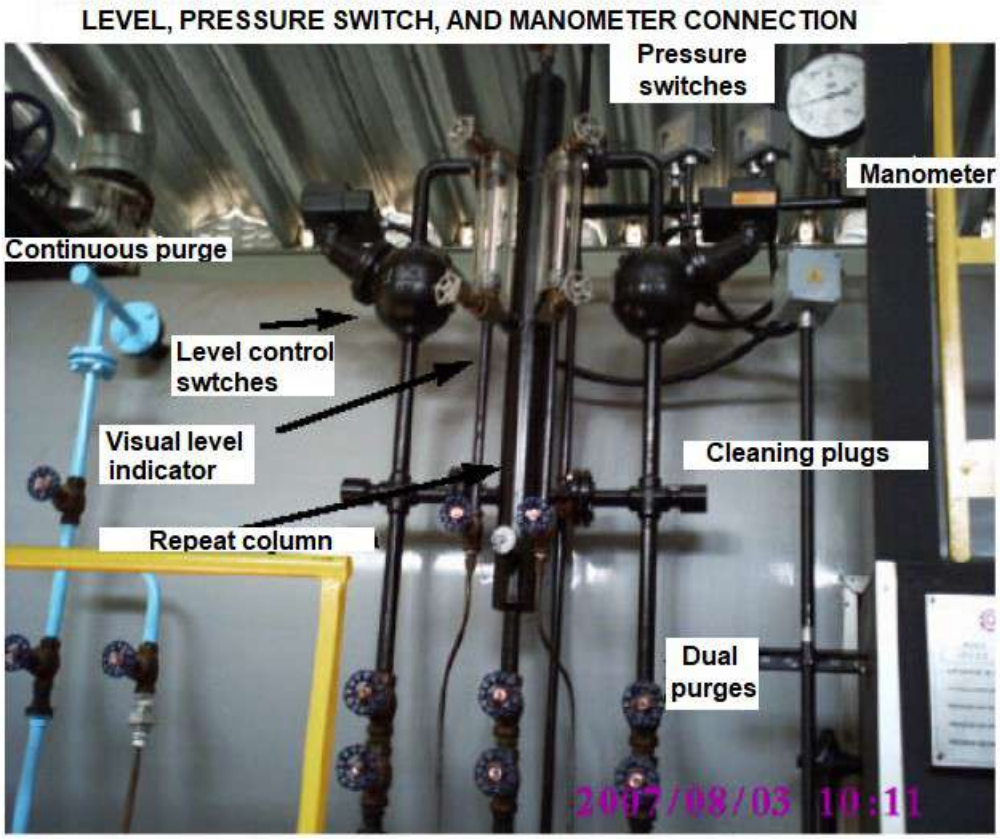
An annual functional check of the pressure gauge ("calibration" or comparison with a standard pressure gauge) must be carried out.

Several faults can occur between the boiler control elements and the connections to the steam chamber (in the case of steam boilers).

These range from human error, such as **installing shut-off valves between the siphons** and the boiler (which should never be done).

But the most common issue is a **leak in the end cleaning plug** of a multi-pipe siphon (for both the pressure gauge and the control pressure switches). This causes corrosion in the siphon pipe, which tends to become clogged (as do the connections to the pressure gauge or pressure switches).

Another fault is that with a European-style tap, the connection to the boiler can be accidentally closed while there is hydraulic pressure inside, resulting in a false reading. This false reading, when used as a reference, can lead to errors.



This system does not include a test valve (because it has two visual level indicators).

The other issue arises when purges are installed at the end of a common siphon and the siphon is repeatedly purged. This affects both the pressure gauge and the pressure switches because they come into contact with the steam instead of the already cooled, condensed water in the siphon (this was an old practice used in boilers due to poor chemical treatments that tended to clog the pressure gauge connection).

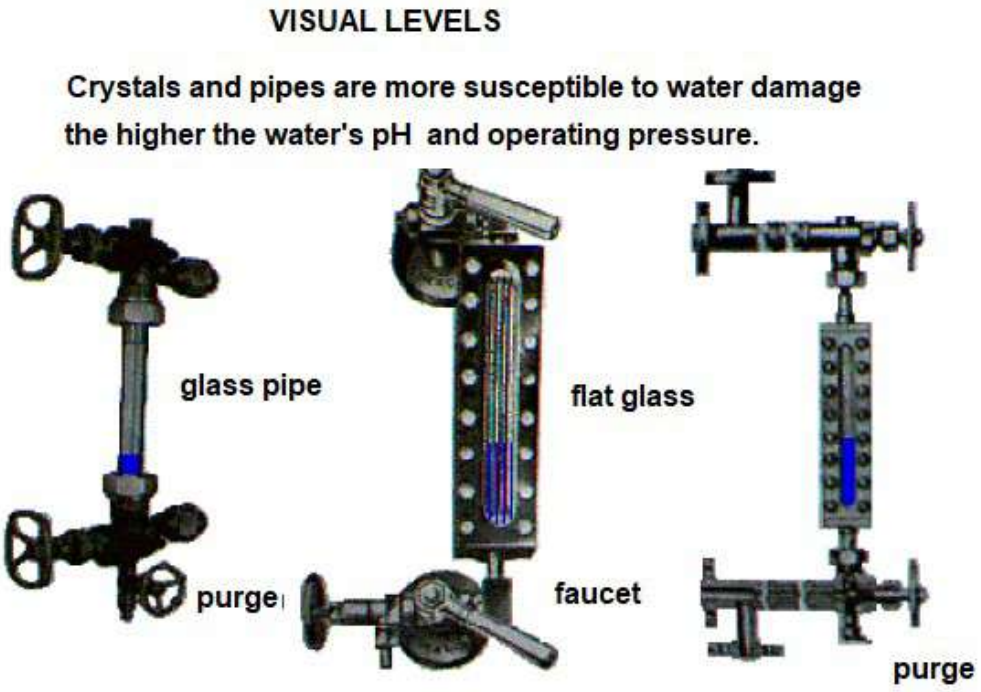
It's common for siphons, and especially the "common" siphon (shared by the pressure gauge and pressure switches), to become clogged due to corrosion. This is because the condensate in the siphon isn't chemically treated by the boiler; it's corrosive condensate, primarily due to the CO2 from the bicarbonates that decompose with heat.

When this common siphon becomes clogged, it can lead to the mistaken belief that the working pressure isn't being reached, even though the safety valves are tripping because the burner isn't shutting off at the correct pressure. (It's advisable to replace this siphon every few years, especially when using well water.)

Levels

The level is used to control and maintain the water level inside the boiler (this is achieved by adding or subtracting the amount of feedwater as it evaporates).

It is as important as, or even more important than, the pressure, because a boiler with insufficient water can overheat and even explode (when it runs out of water, the metal overheats and softens, the spontaneous evaporation of feedwater on the hot metal creates excessive stress, weakening the structure, etc.). Therefore, we will see three ways to control the water level, each one supporting the other two.



Sight glass:

This is a cylindrical glass tube or a "tube" with flat glass faces connected to a column that repeats the boiler's internal water level.

It is connected via valves to the column (allowing it to be closed for glass replacement and blowdown control) and to a blowdown valve (for draining every few hours of operation, for cleaning and monitoring the level return).

The connection to the column is made through small holes or holes with retaining balls, so that if the glass breaks, the loss of water and steam is not dangerous, allowing for the closure of the taps and repairs to be carried out. (An acrylic or tempered glass screen should be placed over the tube for protection when observing, in case the tube or glass shatters.)

Good lighting is essential, and a contrasting background can be used to visually highlight the separation between the water and the steam.

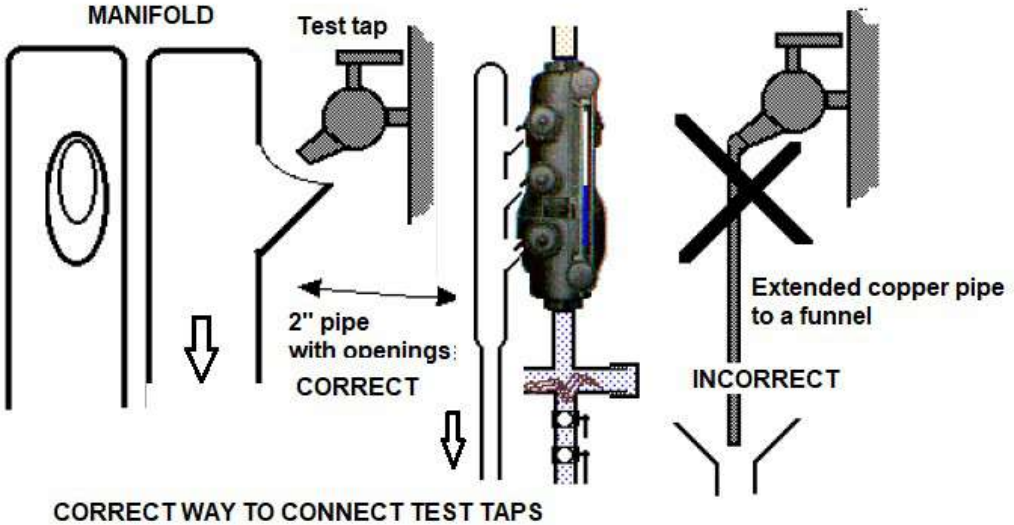
This can be achieved in several ways: on flat glass, by adding grooves to the glass itself; on glass tubes, by adding a colored stripe lengthwise to the back of the tube, or, on the outside of the tube, by adding a background screen with semi-horizontal grooves, generally in black and white.

The crystals and tubes are attacked by the free soda in the water; the higher the working pressure and the soda, the greater the attack on the "glass" of the tube or crystal, causing them to "burst." To prevent this in high-pressure boilers, a "mica" separation is placed between the crystal and the water.

Visual Level Check Valves: These are three valves mounted directly on the repeater column (or hydrometer column) so that we can determine if the water level is at the correct level (the top valve in the steam zone, the middle valve at the normal level, and the bottom valve at the minimum water level zone).

These valves must be tested daily to ensure they are functioning correctly. In case of a visual level failure, these valves provide an emergency visual check of the water level by opening them.

These valves have a discharge design (orifice and length) that allows for the differentiation between water and steam (this was achieved after testing with various valves), as this differentiation is crucial (to avoid confusion between steam only and water with flash steam).



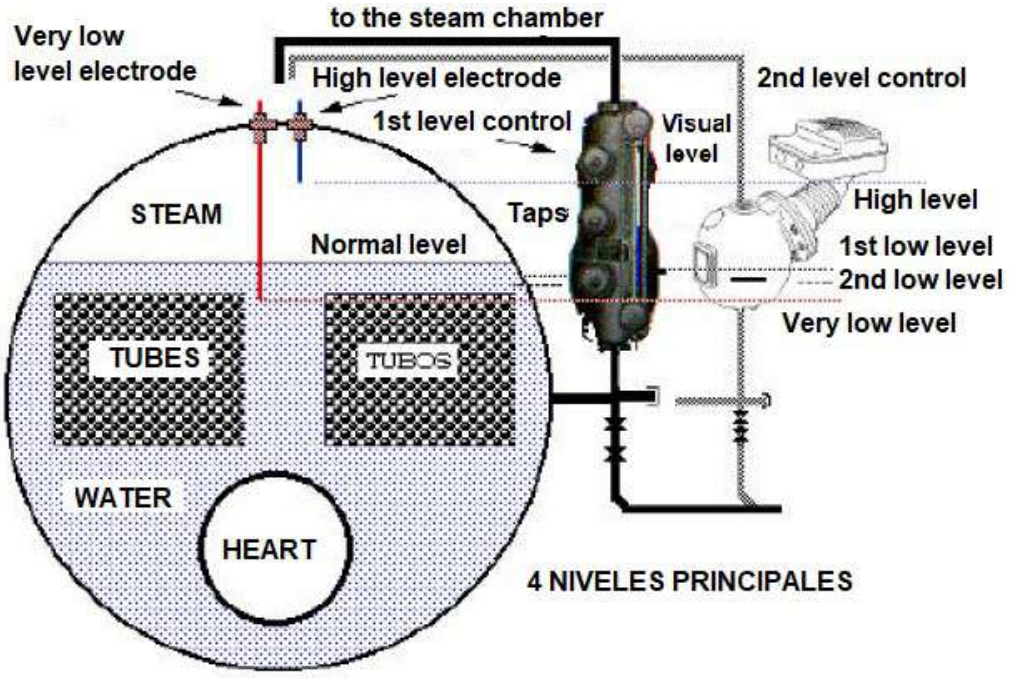
CORRECT WAY TO CONNECT TEST TAPS

Extension pipes should not be installed at the faucet discharge points, as they can obstruct the visual distinction between steam and water. Extension pipes can condense some of the steam, confusing the observer, since hot water also contains flash steam. See last diagram on the right.

If it is desired to collect the discharge, this is done in a pipe of sufficient diameter. Through openings or "cups" located in front of each faucet that discharges into the air, the discharged fluid enters through the opening or cup.

See last diagram on the left.

Never connect the drain manifold or pipe, which is open to the atmosphere, to the main boiler purge system, as bottom purge or level can cause a backflow of hot water and steam that can burn the boiler operator.



Automatic Level Control:

With visual level controls, we can only manually feed the water, and if the boiler runs out of water (low water level), we can manually shut off the burner or "fire" (with the boiler operator always present).

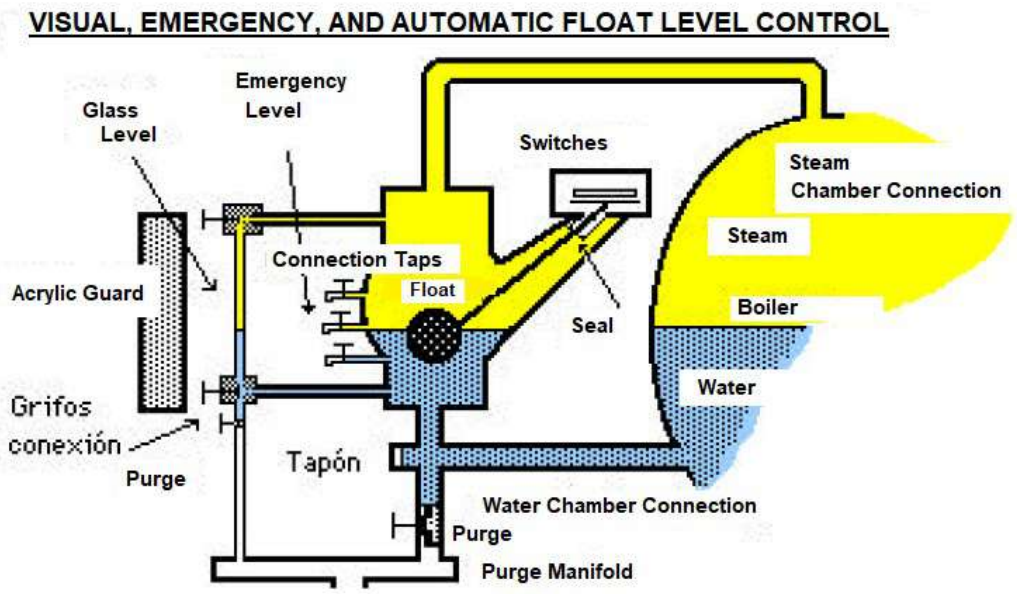
With automatic level controls We can operate the feed pump (turning it on/off or opening/closing the water supply to the feed pump), but fundamentally, in case of a low level: it will shut off the burner or "fires" (wood - cutting off and closing the combustion air and induced draft) and will sound a low water level alarm (alarm and indicator light).

Only when the normal level is restored can combustion be restarted. Shutting off combustion when the level is low is the most important thing.

These level controls can be mechanical (float), electro-electronic (based on **the electrical conductivity of water** by means of electrodes, which makes them vulnerable to problems related to water conductivity and fouling of the electrode's insulating elements by oils, sludge, or scale), or thermal (based on the difference in heat transfer between the steam and water zones in a tube exposed to both).

Mechanical float controls are the most common in low and medium pressure systems. In medium and high pressure systems, other types can be used, such as **differential pressure gauges** (which measure the pressure difference between a column of water at the normal level and the column of water at the actual boiler level; this difference is compared and translated into an electrical or pneumatic value, indicated on repeaters as a percentage of the level or visually by lights for the boiler operator to observe, and in commands for the boiler's feed system and minimum and maximum safety levels).

These level controls must be connected to the boiler body without connection valves (to avoid accidents due to forgetfulness), with purges for their total "purging" every few hours and their connections must have plugs for periodic cleanings (every 6 months or a year, as needed, since they can be blocked by the sludge accumulated inside).



The discharges from the purges to the collectors should have a "deviated" discharge with a curve (to avoid the impact, which causes wear due to erosion of the discharge) or place a stainless steel shock plate on the collector where the discharge impacts.

Modern boilers, regardless of the fuel, have at least two automatic level controls (in case the main one fails) so that they can always shut off the burner due to low water levels (and trigger the corresponding alarm; this second control blocks the burner until the operator re-enables it, after investigating the failure of the first level control and the cause of the low level).

This is due to the high vaporization rates achieved, which mean that a boiler can run out of water very quickly if there is a problem with the water supply (lack of water in the feed tank, a blocked feed pump—due to steam or mechanical issues—failure of automatic feed controls, broken pipes, improper operation, etc.).

The level controls are very important; they must be purged every 4 hours by fully opening the purge valves (and in the case of automatic controls, ensuring that the burner shuts off if it is lit and that the low-level alarm sounds).

The level drains (purge) must be connected to a drain pipe (drain purge manifold) so that the drains can be fully opened to flush out the sludge. (If the drain were exposed to the air, it could not be fully opened due to the risk of burning, and the accumulated sludge, due to the small drain volume, would eventually block the control.)

As the boiler operates automatically with minimal constant supervision, two additional level controls may be present:

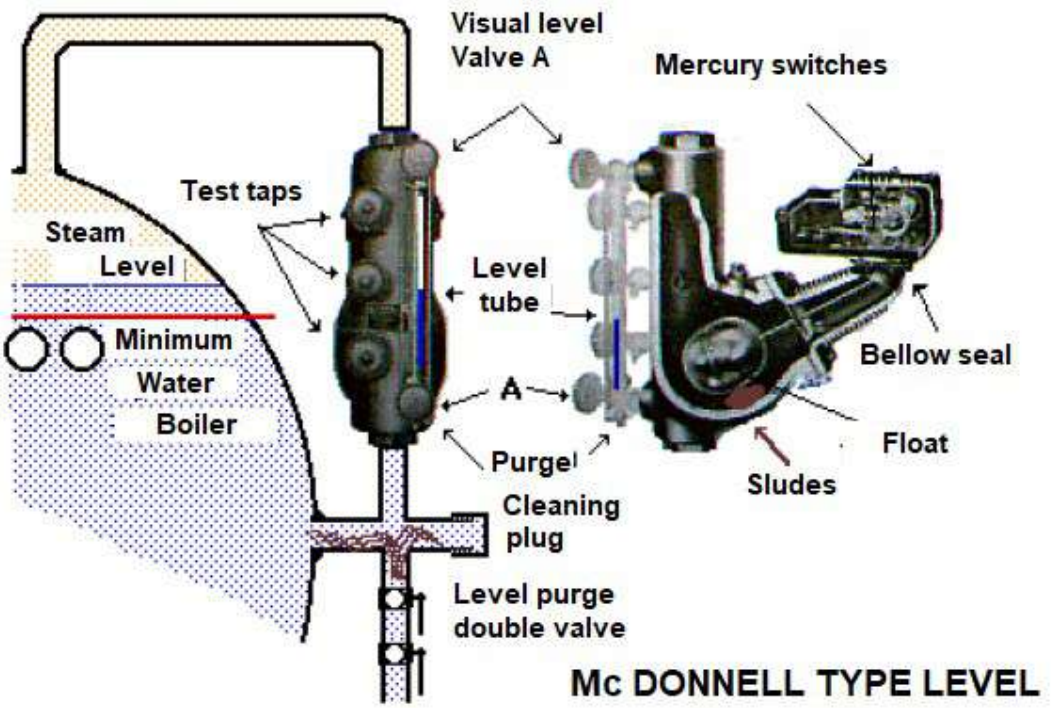
-One for **very low water level** (if the water level drops so low that the primary and secondary levels haven't shut off combustion, but remains above the heat transfer zones, in fire-tube boilers even above the upper tubes), **this very low level cuts power to the boiler's main control panel; shutting down everything, including the burner and feed pumps.**

-The other additional level control may be for **very high water level** (this control cuts power to the control panel and, consequently, the feed pump, preventing the water level from rising further, thus avoiding water carryover from the boiler into the steam pipes; in other words, it protects the steam system, not the boiler itself).

Both levels have audible and visual alarms with manual reset so the operator can understand what is happening.

Generally, both controls operate using conductive electrodes connected to the boiler water and two electrodes with an electrical potential that detects the presence of water (one of the electrodes may be the boiler body itself).

Both controls require resetting the power supply to the control panel (after investigating the cause of the high or low level failure, especially if the first two main level controls failed to detect a low level).



Under no circumstances should the burner be kept lit if the water level is not visible (low or high), nor should water be added until the boiler has cooled down in the case of a significantly low level.

In this case, the steam valve should be closed and the boiler allowed to cool before inspection.

It is possible that the water level is "apparently" not visible because the boiler is "flooded," meaning the water level is higher than what can be seen with the visual level indicator.

In this case, the burner should also be shut off to prevent water from being drawn into the system, which could cause a water hammer effect that could damage parts of the installation.

Water hammer occurs when water enters the steam pipe and gains the velocity of the steam, potentially discharging all its dynamic energy or velocity, like a hammer blow, when it is suddenly stopped at an elbow, valve, or other piece of steam-using equipment.

As shown in the previous diagram**: it is not advisable (and should not be) to connect automatic level controls that cut off combustion due to low water level to the boiler via pipes with shut-off valves** (only visual level gauges should have shut-off valves to isolate them from the boiler in case of glass breakage, both to prevent loss and facilitate repairs).

If there were a shut-off valve on an automatic low-level cut-off system, there would be a risk that, due to error, oversight, or malicious intent, a valve could be left closed, preventing the level control from responding and causing the boiler to run out of water, resulting in an accident due to insufficient water level in the boiler (the most common type of accident, with unpredictable consequences).

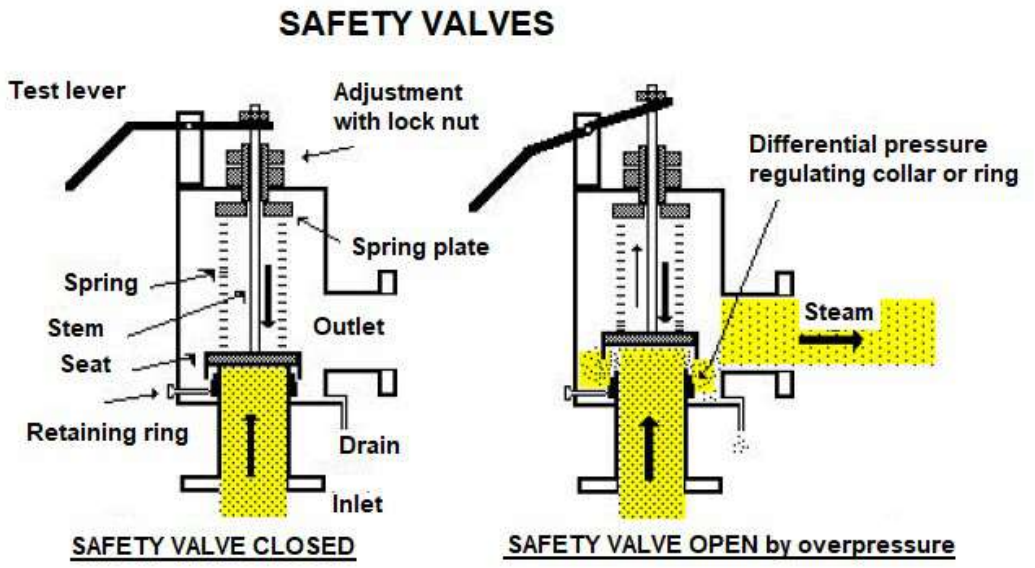
BOILER FIRE CRUSHED BY LOW WATER LEVEL

Due to a failure of the automatic level shutoff,

the burner did not turn off when the water level became low.

Often, these valves are installed under the pretext of improving level control or facilitating repairs in case of failure, but the danger far outweighs any practical benefit: **don't do it!**

It's preferable to open the level controls every few months if sludge buildup is suspected (even if they are purged every 4 hours of operation) **to clean it out** (generally, when a water softener isn't used, there's a lot of sludge in the boiler water).



Safety valves are installed at the top of the saturated steam chamber and at the superheated steam outlet.

Safety valve function is to limit the pressure inside the boiler to a maximum (this pressure is the maximum permissible working pressure, called the "ringing" pressure) by releasing excess steam to the atmosphere.

The boiler pressure can rise if the burner is not shut off in time (if it is manually operated) or if the automatic control (pressure switch) fails when the maximum (cut-off) pressure is reached.

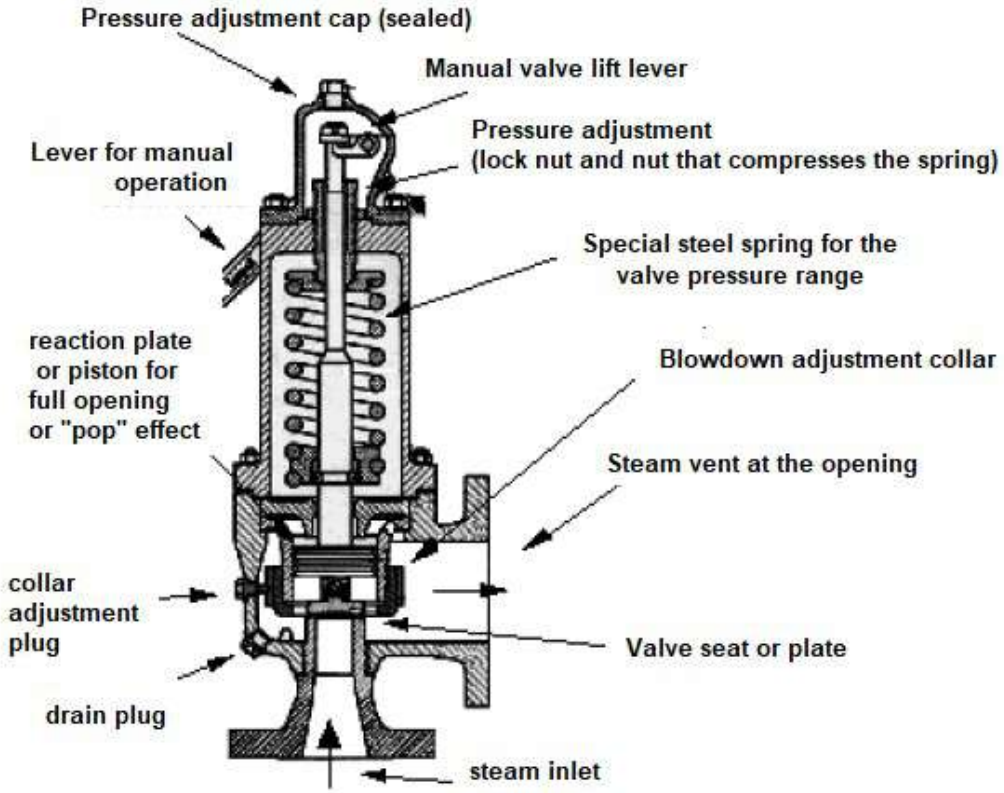
Do not confuse boiler safety valves with relief valves for steam, gases, or liquids

Boiler safety valves have notable differences:

- **They are fully opening** (or have a "pop" effect—like pulling a cork out of a bottle—necessary because the boiler generates internal pressure).

- **They have an adjustable device that allows the closing pressure to be lower than the opening pressure** (pressure differential—"blowdown"—generally adjustable with a collar on the seat).

- **They have a "lever" that allows for testing** (opening without reaching the set pressure to keep the mechanisms "free" or prevent them from seizing), by operating them periodically (weekly).


Pressure adjustment cap (sealed)
Manual valve lift lever
Pressure adjustment
(lock nut and nut that compresses the spring)
Lever for manual operation
Special steel spring for the valve pressure range
reaction plate or piston for full opening or "pop" effect
Blowdown adjustment collar
Steam vent at the opening
collar adjustment plug
Valve seat or plate
drain plug
steam inlet
BOILER SAFETY VALVE

The springs must be within the expected operating range.

The **capacity of the safety valve kg of steam/hour,** to be evacuated in case of steam overpressure in the boiler, will be that calculated according to the standards used (no less than all the steam capable of producing the boiler under any condition, with the burner at maximum.

Generally, this capacity is achieved with two valves (except for very small boilers), or more.

To adjust the opening pressure of safety valves, they generally have a nut (with a lock nut) that adjusts a spring which pushes against the seat plate.

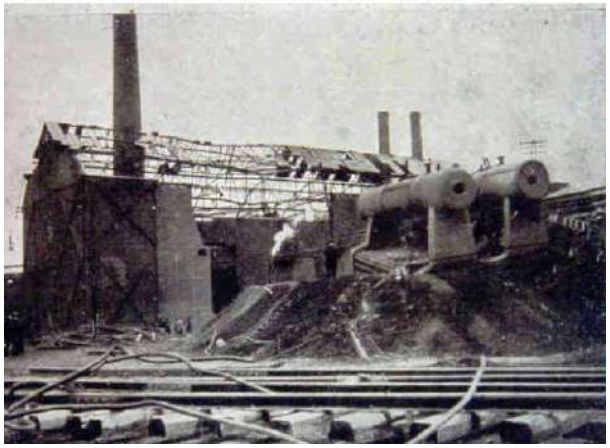
The greater the pressure on the seat, the higher the opening pressure. These valves can initially be adjusted with a hand pump for hydraulic testing, but then they must be readjusted in the boiler (since the adjustment can be affected by the temperature).

When adjusting the valves, care must be taken not to exceed the maximum allowable pressure ("ringing pressure") and not to let the pressure rise more than 6% above the maximum allowable working pressure (once the valves are open and vaporization is at its maximum).

The closing pressure is regulated according to the type of boiler and fuel (approximately 1% to 6% below the opening pressure).

The exhaust must be vented to the atmosphere through a sturdy pipe of the appropriate diameter (preferably separate from other exhausts and from itself) and in a way that prevents the steam from burning anything or anyone (the exhausts are very violent!).

Normally, a minimum of two valves are required, and they must open at different pressures (to avoid excessive decompression and often unnecessary steam loss). See below.



Never remove or operate without SAFETY VALVES: they are the only protection mechanism against steam over-pressure in the boiler in case the pressure switches or the "boilerman" fail to supervise.

Transport of the boiler of the Minas Electric Power Plant, September 1902, URUGUAY
http://bibliotecadigital.bibna.gub.uy:8080/jspui/handle/123456789/10748

CHAPTER 4: Components of a Boiler Part 2

Pressure Switches

These devices control steam pressure and start or stop the burner. They are connected in the same way as the boiler's pressure gauges and consist of a pressure-sensitive element (a special bronze or stainless steel bellows, compressed by springs with adjustable force via nuts and bolts; a system of levers actuates electrical contacts).

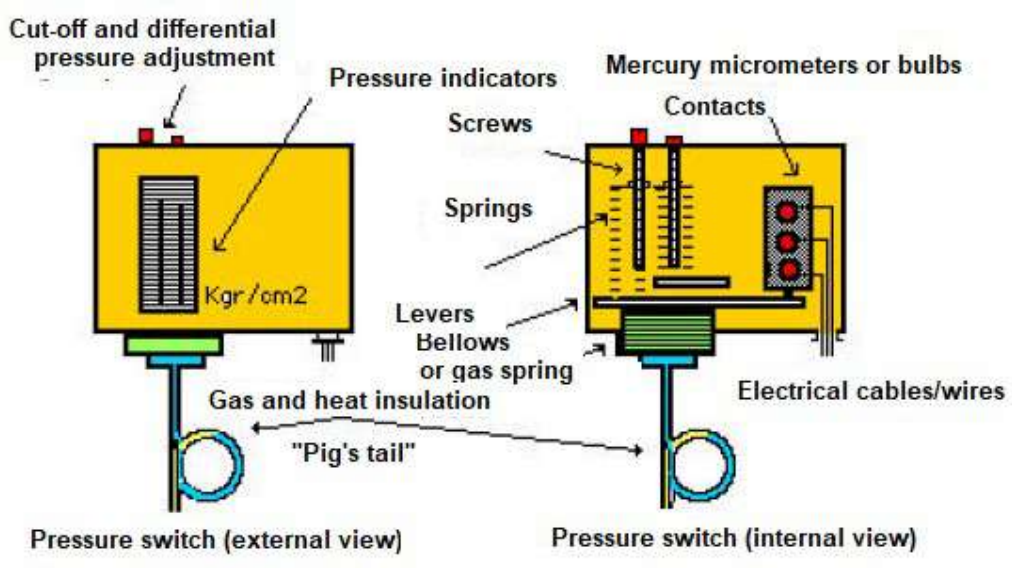
The actuation of this element on contacts can be adjusted so that a contact can "open" at a specific pressure (high-pressure cutoff) and "close" at a lower pressure (burner start-up).

The difference between the high pressure (cutoff) and the lower pressure (start-up) is adjustable (called the "differential"), allowing a boiler to start at a specific pressure and shut down at a higher one.

These elements must be connected without valves and by means of gas and steam temperature insulators ("pigtails", chambers or "U-tubes") to prevent corrosion and weakening of the bellows (due to temperature).

These pressure switches must be adjusted to operate at the desired cutoff (turn-off) or start-up (turn-on) pressures. To do this**, the cutoff pressure (normally) must be adjusted first, and then the start-up pressure (start-up) is adjusted by turning on the differential screw.**

Never create an electrical "bridge" to eliminate a pressure switch, as the only thing that can limit the pressure will be the safety valves.



Do not install valves between the pressure switches and the boiler.

Clean the connections once a year: disassemble, blow through with air and water, and use a cleaning cloth if necessary. There should be no steam or water leaks when reassembled.

To observe the operation and the start ("connect") or cut-off ("disconnect") pressure values, check the pressure on the boiler's pressure gauge in each case, as the settings for these pressure switches are approximate (not exact).

In wood-burning boilers, pressure switches operate the forced air and induced draft systems to control the air and combustion gases (to "shut down" combustion, the air inlets are turned off or closed—turning off or closing the forced air and induced draft systems).

This creates a lack of oxygen for continued combustion, which is restored when air is allowed to enter again as the wood remains incandescent among the ashes (coal).

There are pressure switches (modulating) that, instead of contacts, have a variable electrical resistance, allowing them to control a "modulating" motor (which, instead of turning on and off, moves slowly from "closed" to fully "open" and stops at the set pressure point). In this way, we can control a burner continuously (whether wood, oil, or gas): this is the ideal control method.

Boilers may have more than one pressure switch, as there can be an "extra" overpressure switch.

Which, in case of failure of the first one, cuts off at a higher pressure, shutting off the burner, triggering an alarm, and requiring manual reset.

The manual reset is very important, as it alerts the boiler operator that the high-pressure cutoff switch is failing.

The operator will have to perform the manual reset, and it is advisable to replace the high-pressure cutoff switch, as it will fail again, provided there was no other cause for the very high pressure, but before the safety valves activate.

For safety, there may be two pressure switches: one for start and stop, and a second pressure switch to operate the burner with a "high" flame (semi-modulated, with two flames: low and high) or with full modulation.

A third pressure switch for a third flame (semi-modulation, 3 flames: low, medium, and high, aiming for continuous modulation).

The ideal operating condition of a boiler is to maintain the pressure as close as possible to the desired operating pressure and for the burner to remain lit, adjusting to the needs of maintaining that pressure (which will vary according to steam consumption; this is called continuous modulation, and it makes the boiler more economical or efficient than if the burner were to cycle on and off).

Fusible Plugs

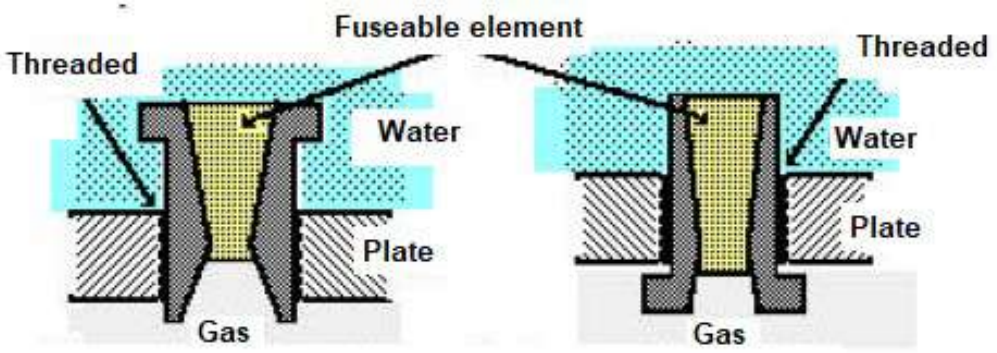
Fusible plugs (which melt when heated) are required as standard practice in low-pressure boilers (generally fire-tube boilers).

These plugs are shaped like a cap (made of copper alloy) with a threaded connection and a central hole filled with a material that melts at a specific temperature (generally pure tin, which melts at around 230°C, although special alloys may be used in some cases).

These fusible plugs are screwed onto areas (plates or sleeves) below the water level in the boiler. These areas will superheat as the water level drops, melting the center of the plug and allowing the steam pressure to escape (inside the flue gas passage or, in some cases, to the outside).

They must be replaced whenever they leak, melt, undergo chemical cleaning, or twice a year as a routine maintenance.

Do not attempt to refill a melted plug yourself or replace it with a blanking plug: **replacement plugs must always be original (supplied by the boiler manufacturer).**



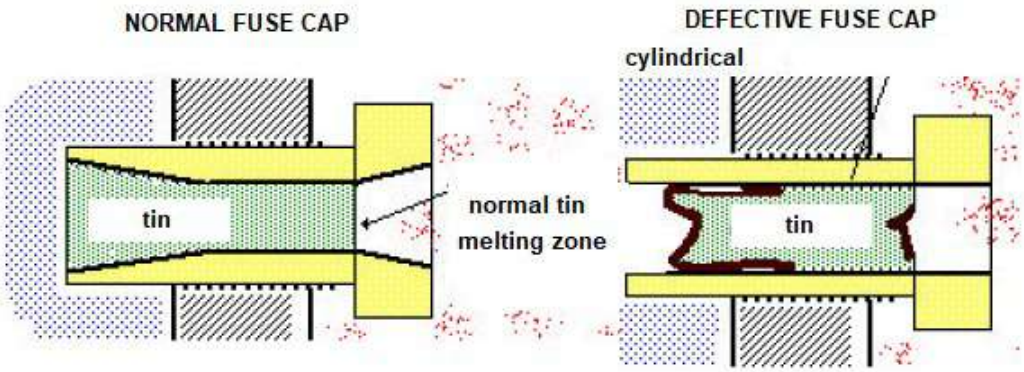
Fuse Plugs: Water side threaded - Gas side threaded

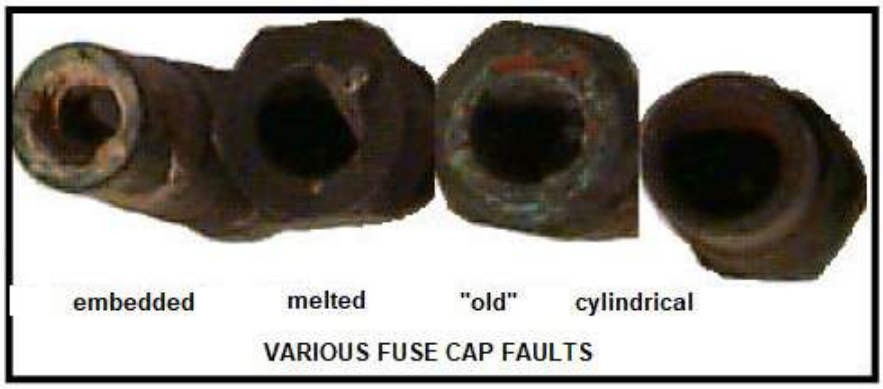
If you encounter a boiler with a melted fusible plug, a thorough inspection should be carried out to check for overheating (tube leaks, misaligned plates, deformed combustion chambers, etc.).

An additional hydrostatic test should be performed after replacing the fusible plug.

Otherwise, there is a risk of an accident, as a melted fusible plug indicates a loss of water level.

It is possible that a faulty fusible plug can melt over time (lack of taper, contaminated solder, insufficient cleaning during the melting process, such as when refilling the boiler).





The Feedwater Pump

Feedwater pumps perform the function of drawing feedwater into the pressurized boiler (replenishing the water that evaporates and maintaining the boiler's water level).

The feedwater in the pump is subjected to a process that increases its pressure above the boiler's internal pressure, overcoming the check valve, friction (pressure losses) in the pipes, and the internal pressure, and entering the boiler.

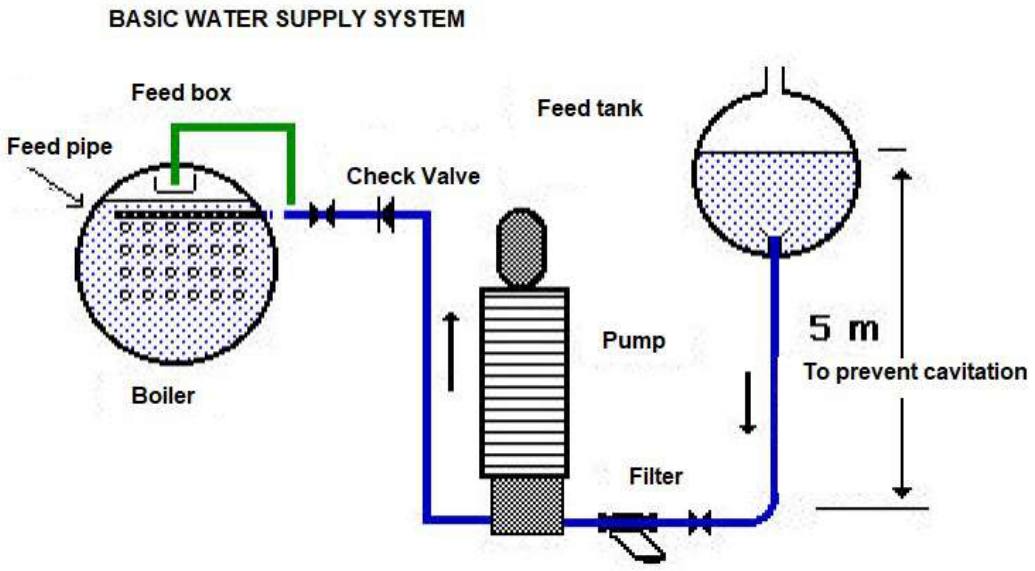
This check valve allows water to flow in only one direction, preventing the boiler from emptying when the pump is stopped or when the pressure is lower.

The pumps draw water from the "feed tank." This tank must be elevated at least 3 meters (ideally 5 meters) above the feed pump to ensure the pump is supplied with sufficient water pressure to prevent cavitation (the pump stops pumping, and steam bubbles or plugs form due to the suction vacuum approaching the boiling point; this problem worsens as the water temperature rises).

The feed water is heated because it is a mixture of condensate (hot to 100°C, 212°F in many cases) and cold makeup water.

If the feedwater is cold, it is advisable to heat it, if possible, to above 80°C (176°F) to avoid thermal shock with the water inside the boiler, which is at over 100°C (212°F) (depending on the operating pressure), and to expel as many dissolved gases as possible.

Furthermore, the boiler will also perform better when fed with hot water (since hot water requires less heat to reach the vaporization temperature plus the heat of vaporization, which together is the sum of the sensible and latent heats).



Water supply can be continuous: by regulating the boiler's inlet valve (opening or closing smoothly according to demand: modulating) manually or automatically.

Or it can be intermittent: by turning the feed pump on and off (manually or, generally, automatically: On-Off).

There are several types of feed pumps, not only because of how they "boost" the pressure, but also because of the type of energy used for their operation.

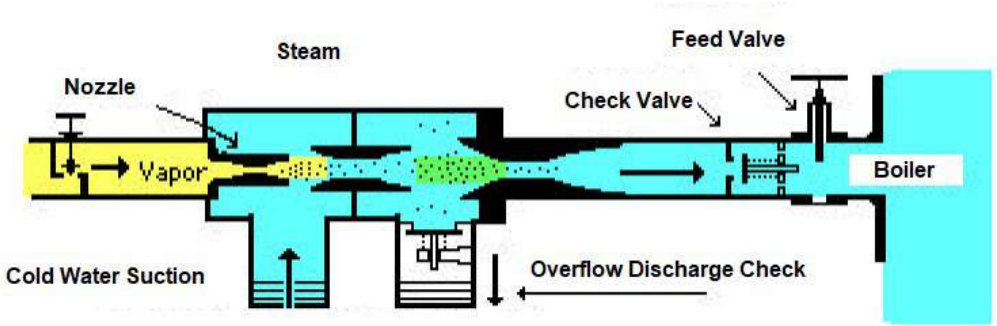
Therefore, we will find that not all types of feed pumps are suitable for continuous supply (which is ideal).

Feed types: via steam injector. It utilizes the energy of the steam from the boiler itself to propel the cold feedwater through a nozzle and diffuser.

As the steam condenses, its velocity increases, "pushing" the cold water and increasing its pressure, which overcomes the resistance created by the boiler pressure.

Its operation is continuous; regulating the flow of "live" steam to the injector somewhat regulates its capacity.

It is normally used as an auxiliary feed (especially in wood-fired boilers during power outages, to prevent the boiler from running low).



STEAM INJECTOR

Within the category of steam-driven pumps, we have several types:

Steam-driven pumps (steam turbines or steam reciprocating pumps: "donkeys"), which can be piston pumps (reciprocating) or centrifugal pumps (with sliding or "regenerative") driven by steam turbines.

By regulating the speed of the steam turbine, the water flow rate can be regulated, and in steam turbine pumps, it can be regulated with the pump's discharge valve (since they are sliding centrifugal pumps whose revolutions remain constant).

Electrically driven pumps are the most common. These include piston pumps (less common), centrifugal pumps of the "sliding" type, and "regenerative" (semi-positive displacement) type.

Piston pumps and some "regenerative" centrifugal pumps can only operate in an on-off mode.

Otherwise, their pressure would rise to levels that would stop the motor, or their energy consumption would be very high (unless a relief or regulated return system is installed).

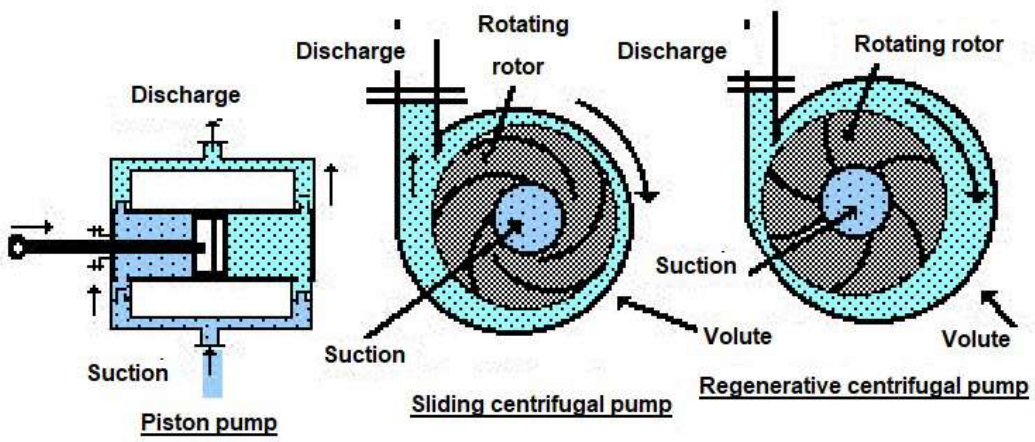
Sliding centrifugal pumps can operate in an on-off mode or by regulating the flow with the supply valve manually or automatically (since these pumps consume less energy when their discharge is closed, even if the pressure increases).

Centrifugal pumps operate based on centrifugal force (the force that tends to separate a body from its axis of rotation, for example: the bolas used by gauchos or David's sling).

Since each pump diameter and a specific rotational speed (RPM - revolutions per minute) corresponds to a specific pressure, several stages are used to increase the total pressure achieved.

The difference between a **"slip" pump and a "regenerative" pump** generally lies in the fact that a "slip" pump, by closing its discharge valve, reduces the energy consumption of the motor that drives it, while a "regenerative" pump increases energy consumption (similar to "positive displacement" pumps: gear pumps, for example, when a gear pump closes its discharge, the pressure increases to such high levels that it can rupture the discharge pipe or stop the motor).

The advantage of the regenerative pump in some cases is that it can achieve higher pressures with fewer stages, and in other cases, it has good suction characteristics (low risk of cavitation). However, in general, they are inefficient (consuming more energy than necessary).



In **centrifugal pumps**, the rotor (impeller) is made up of single (open rotor) or double (closed rotor) discs containing the vanes (curved ribs that propel the water as the impeller rotates).

This rotor is located inside a volute (pump casing or housing) that encloses the rotating water and, according to its shape, captures this rotating water flow and diverts it to the outlet pipe, thereby increasing its pressure (based on the energy it has taken from the impeller).

In all pumps, suction occurs because the water displaced by the discharge leaves a "free" space that tends to be filled by water from the suction pipe, "pushed" by atmospheric pressure (acting on the free surface of the tank or well).

Therefore, the suction of a cold water pump can be taken from a depth of approximately 7 meters (22.9 ft) (remember that atmospheric pressure is 10.033 meters (32.9 ft) of water column at sea level), but due to the vapor pressure of water (which varies with temperature) and friction losses in the pipes, this suction will be less than atmospheric pressure.

Pumps feeding hot water must be fed with positive pressure (above atmospheric pressure, i.e., the tank above the pump) and

not, as in the case of cold water, which can be "suctioned" from below the pump (pressure below atmospheric pressure, negative gauge pressure).

The diagram above (very basic) illustrates the difference between a **sliding centrifugal pump and a regenerative pump**. Note that in the latter, the forward-curved impeller vanes "push" the water towards the outlet, which causes the pressure to rise when the discharge is closed, increasing the energy required for pumping.

In the case of **sliding pumps**, the backward-curved vanes tend to "slide" when the discharge is closed, and since the water volume decreases (but not the pressure), energy consumption decreases (the pump can and should be started with the discharge closed to reduce the starting force).

Regarding centrifugal pumps, it's important to note that the pressure depends on the rotor's rotational speed (RPM - revolutions per minute) and its diameter, as well as the number of rotors in series (stages). The water volume of each pump depends on the discharge and suction pressures (pressure vs. volume curve).

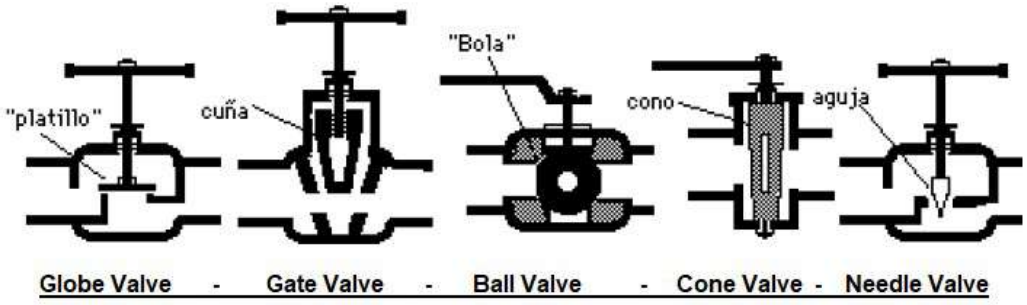
Furthermore, the impeller shaft must be sealed to prevent air from entering the suction line or water from leaking.

This sealing can be by "packing" (cords of material pressed in a "stuffing box": cotton, asbestos, Teflon, etc.) which must be adjusted periodically (or changed and which must lose a drop of water every so often for lubrication) or a mechanical seal (a ring of hard material: stainless steel, ceramic, etc. that rests against a soft and low friction material: carbon, graphite Teflon, etc.) with the great advantage of not needing maintenance (only changing in long periods) and which produce a very good seal (it is lubricated and cooled with the same water that it propels).

Valves

Valves are devices used to open or close the flow of a fluid (water, steam, etc.) in a pipe.

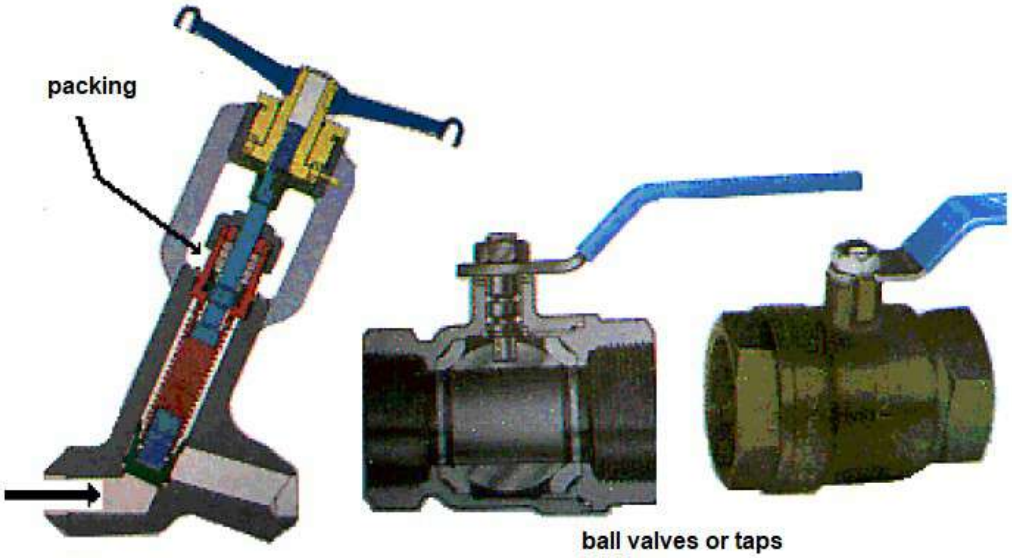
There are several types of valves: globe (disc), gate (wedge), ball, needle (a needle in an orifice), cone or cylindrical tap, piston, etc.



They all have different qualities for their use: globe valves allow flow regulation without significant wear, gate and ball valves can be "full flow" (they do not restrict the flow - they should not be used for regulation), ball, piston, and tap valves can be quick-acting (quick opening and closing), and needle valves allow for very "fine" regulation.

Valve seats can be made of hard materials (steel, chromium-nickel steel, etc.) or soft materials (such as bronze, Teflon, Micarta, etc.) or a combination thereof. Some seats are replaceable (the soft ones) while others (the hard ones) can be ground.

Valve bodies are made of materials such as cast steel, alloy steels, gray cast iron, bronze, etc. (depending on their application). Therefore, there is a classification system that must be followed for their use (very important due to the pressure and temperature they must withstand).

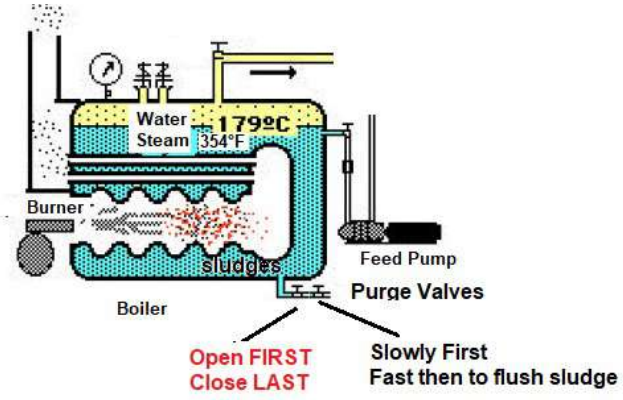


Valves for use in steam systems have a classification ("Series" 150, 300, 400, 600, etc.) that indicates the maximum pressure and temperature range for which they can be used.

A similar classification is used for pipes: the "Schedule" (20, 40, 80, etc.) indicates the wall thickness of the pipes.

Purge valves may be paired (this is advisable for safety): one slow-acting valve against the boiler and another fast-acting valve outside (both full-flow).

The operation should be performed by opening the valve against the boiler first and closing it last—opening the external valve slowly at first (to heat the pipe and then quickly to flush out the sludge).



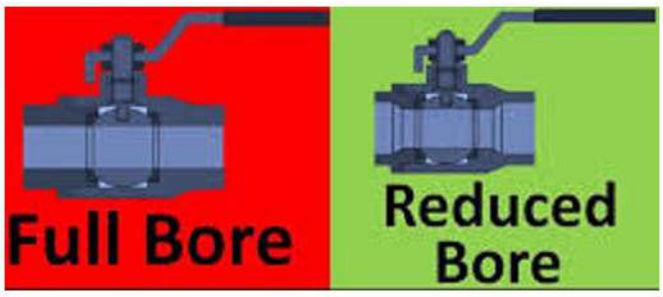
Valves must be operated with extreme care when under pressure from steam or hot water, and drain valves even more so (as they allow the boiler to be emptied in case of a rupture or failure to close).

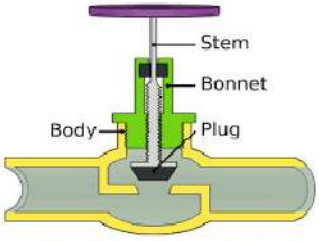
Steam valves should be opened gently, warming the pipes to prevent water hammer (the violent condensing of cold water and steam, which propels the water at high speeds against the pipes) and to account for pipe expansion (1 mm per meter per 100°C 212°F).

However, they must be fully open (to prevent "scoring" of the seat by steam, unless they are valves for regulating special seats: due to their shape and material, globe valves are more suitable for regulation).

A valve of one type should not be replaced with another type without first explaining the reason for the valve's selection.

A full-bore valve is understood to have been installed for complete opening and closing (with almost no pressure loss), and replacing it with a globe valve (with restricted flow) can generate a pressure loss that impairs operation, etc. (therefore, respect the "Series" classification).





Globe Valve (reduced bore)

The pipes are connected by fittings made of the same material and valves. These connections can be threaded, welded, or plated.

The threads must be sealed with a material appropriate for the temperature and pressure at which they operate (for example, in hot water: **Teflon tape (temperatura and steam clasified)** or paste, or a homemade paste such as red lead, graphite, and well-boiled linseed oil, or litharge and glycerin (for light fuels, some gases, etc.), or in cold water with hemp-based sealant, etc.).

The plates will be fitted with gaskets suitable for the pressure and temperature (Klinger, asbestos, specially shaped metals, graphite, etc.), using graphite flakes mixed with grease or oil (on both the faces and threads of the plate screws, which must be tightened evenly). See the chapter on gaskets and seals later.

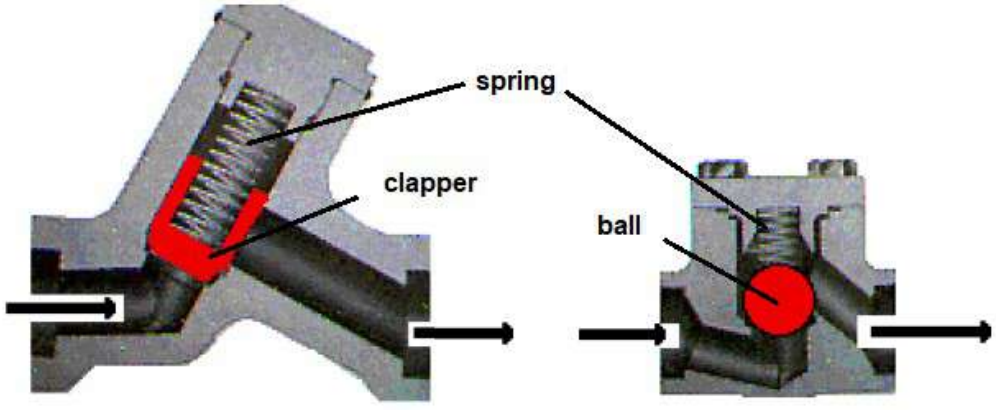
Check valves

Are used to force flow in only one direction. They can be divided into: axial type (vertical, axial lift with guide) or swing type (or "flap" type, which can be 90° or 45°).

Swing valves have lower pressure losses, and the 45° type is ideal for steam and condensate flow (which require rapid opening and closing).

The comments regarding valve materials and their "Series" classification are also valid. Ball check valves perform well as check valves for boiler feedwater.

When more than one boiler is installed in parallel, check valves (suitable for steam) are placed at the steam outlet of each boiler (so as not to pressurize the lower-pressure boiler with the higher-pressure one—this is important not only for mechanical and safety reasons, but also for chemical reasons, as corrosion occurs).



CHAPTER 5: Operation Part 1

We will examine the normal operation of the boiler and then address emergencies and maintenance.

We have seen that the operation of a steam boiler can be summarized as follows:
1- Maintaining a specific steam pressure (corresponding to a single saturated steam temperature). This pressure depends on the "demand" or steam consumption and the amount of "fire" or fuel burned at any given time. Since consumption is determined neither by the boiler operator nor the boiler itself, but rather by the process or location where the steam is used, the pressure will be maintained based on the amount of "fire" or combustion.

This balance between the amount of energy delivered by the boiler in the steam and the amount of energy delivered by combustion can be maintained manually or automatically (by regulating the fuel and air: continuous modulation, or by turning the burner on and off: "On-Off", or by regulating the air only: wood).

The difference between these two energies (steam and combustion) are the boiler losses (losses in the heat of the flue gases, heat losses from the boiler itself to the boiler room, water and steam losses in the boiler, purges).

2- **Maintain a specific water leve**l (covering the heat transfer surfaces, but not filling the steam chamber, which could lead to water being carried along with the steam: foaming, priming, carryover, etc.).

This water level (with minimum, normal, and high levels) can be maintained manually or automatically by regulating the feedwater inlet.

This level depends on, or tends to vary with, the steam demand or consumption, due to the need to evaporate a greater or lesser amount of water, and the need to replenish the feedwater to replace the evaporated water.

The feedwater can be regulated by: turning the feedwater pump on and off (On/Off control), or by regulating the inlet valve or the feedwater pressure (continuous modulation).

The level may vary due to temporary changes in the boiler's internal conditions (when a cold boiler is started, the level tends to rise as the water heats up; when there is a rapid increase or decrease in steam consumption,

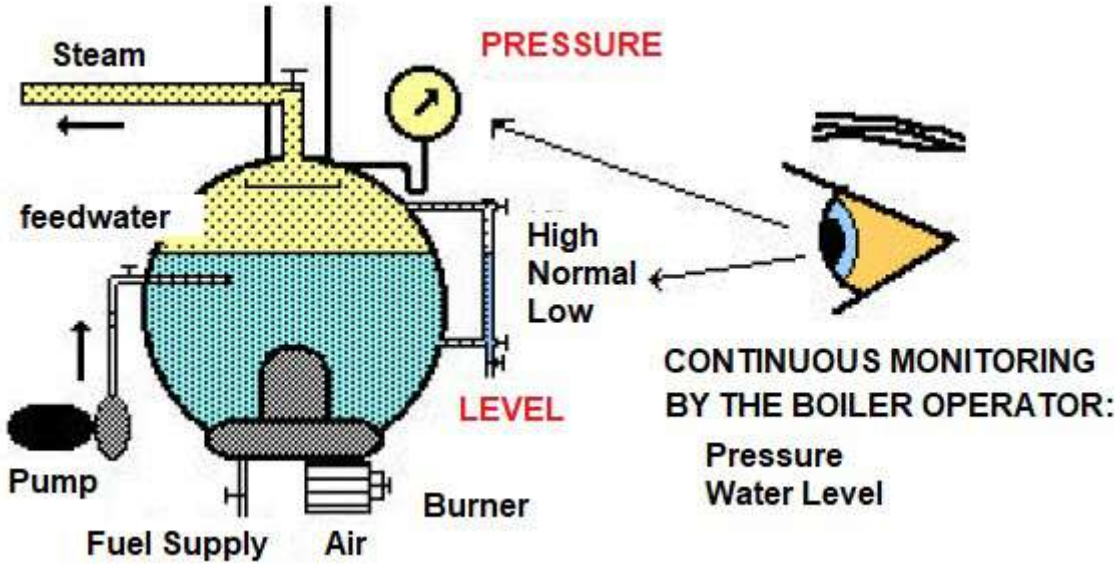
the water level appears to rise in the first case and falls in the second). Certain chemical conditions also cause the level to fluctuate.

In all these cases, caution should be exercised, as these are temporary conditions that do not always need to be corrected, since a momentarily low level can quickly become a high level.

The boiler operator must pay close attention to the pressure and water level, as these are the two variables necessary to operate the boiler, even if it is automatic, and these will be the first things to check when performing a maintenance check.

The balance between **the amount of steam and the amount of combustion** required is controlled by the **pressure**.

The balance between the **amount of steam and the amount of feedwater** required is controlled by the **water level**.



Constant monitoring of pressure and water level are the two fundamental aspects of boiler operation.

If we don't control the pressure (by adjusting the combustion quantity), the steam quality (temperature and humidity) will not be adequate for the process and safety. As pressure rises, we will depend on safety devices: **safety valves**.

If we don't control the water level, we can "burn out" the boiler due to a low level (overheating of the heat transfer surfaces or rupture with an

"explosion"), or we can produce wet steam due to a high level (and even water carryover with "water hammer" that can cause equipment damage).

Combustion quality must be constantly monitored by observing the **appearance and color of the flame**, as well as the presence and color of the flue gases.

Alternatively, the air-fuel ratio can be monitored by reading the excess air required using instruments that measure oxygen or carbon dioxide in the flue gases.

This prevents the presence of carbon monoxide, excessive smoke, or an excess of air that could lead to greater losses in the flue gases.

Once the pressure and level are constant, we must focus on maintaining the conditions of the feedwater and the water inside the boiler.

To this end, the "ion exchanger" equipment (water softeners and demineralizers) will be monitored by taking samples periodically to control water quality (Total Hardness in softeners and Water Conductivity in demineralizers, etc.).

The temperature of the feed water must be kept at a preset value (as high as possible according to the feeding system) and care must be taken with the chemicals that must be introduced into the water (the quantity and the way of putting them in: continuous or discontinuous, etc.).

The **boiler water, monitored by analysis**, must be maintained within specific limits, not only by **adjusting the chemicals** used but also by regulating the amount of purges, both deep and continuous.

For safety reasons, the level controls must be purged every 4 hours, ensuring the low-level alarm and shut-off are properly opened.

As we have seen, we must **remove the dissolved solids** (T.D.S.) and **sludge (salts and insoluble elements**, formed intentionally or by natural chemical reactions, depending on the quality of the makeup water, pipe oxides, etc.) from the boiler.

Bottom purge (which remove sludge and dissolved salts) should be performed at least once per shift and as often as necessary depending on the treatment and type of makeup water.

Open the valves fully during periods of minimal steam production, or better yet, with the boiler off. The sludge will tend to settle, lowering the level by one to three centimeters, depending on the boiler. Repeat the purge if necessary once the level has recovered.

With the boiler running: never purge water-walled collectors.

Check the proper functioning of the purge system by listening for the noise produced by the flow of water and flash steam.

Otherwise, the purge could be blocked by debris or precipitates. These could be elements that have fallen into the boiler during repair or inspection, or simply loose scale fragments stuck in the valves or piping.

In the case of the bottom purge, you can check for a drop in the water level, but not in the purge of the level controls.

A failure of the bottom or level purge can have serious consequences for the boiler's internal circulation (overheating) or can cause the level controls to malfunction (low water level failure).

The continuous purge should be opened as needed (it removes dissolved salts and affects the Total Dissolved Salts - TDS), and generally fractions or liters per minute are removed, monitored with a measuring device (a graduated jug or "jar" at a specific time, which will be adjusted each shift).

There may be times when purge is necessary due to observations (like **excessive fluctuation in levels**: this could be due to insufficient purge or contamination of the boiler water, excessive bulk treatment, etc.).

In these cases, continuous purge should be performed until the level fluctuations subside (which can also be due to excessive or irregular steam consumption: in these cases, purge is not a priority, but it can help by lowering the chemical limits of the water, thus reducing the possibility of carryover), although it is advisable to shut off non-essential steam consumption.

Observe the appearance of the materials, especially in the combustion chamber, for signs of overheating or slag (clumps of unburned fuel) that could affect proper combustion. (Slag should be removed or broken up every shift.)

Purge the manual emergency level controls (level indicator valves) and test the safety valves at least once a week (by pulling the levers provided for this purpose).

In fuel oil burners, maintain the burner system at the specified conditions, temperatures, and pressures.

Clean the atomizing nozzles (or cups in rotary burners) periodically, taking care not to enlarge their orifices.

We have observed that if the fuel temperature drops, it becomes more difficult to pump and atomization is poor (producing soot even with excess air).

Check the auxiliary ignition system (propane in most cases; verify the gas supply and the pressure regulated to the ignition burner: pilot light).

Check for water leaks (pump and valve stem packing) and steam leaks. Cleaning the boiler and the room is essential.

BOILER START-UP

When starting a boiler, the first step is to check all the components involved in its operation:

1- Verify that it is **filled with suitable water** (softened, chemically treated, etc.) to almost the normal level (1/4 of the visible level or the pump's automatic cut-off point, as the level will rise as the water temperature increases).

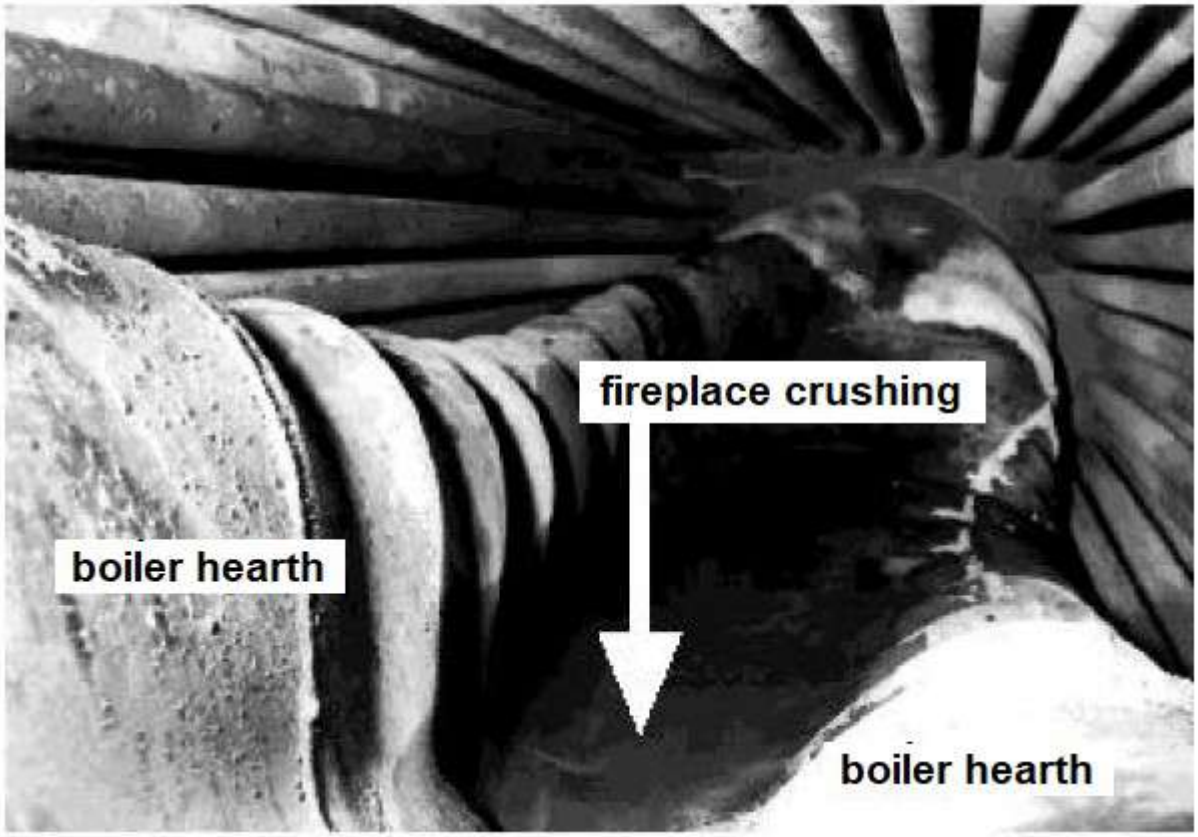
To fill the boiler, close all the purge valves and open the atmospheric valve (air vent).

It is assumed that the **main steam valve (throat valve) is closed**.

If the boiler is being "preserved" using a dry method, the drying agents (such as quicklime or silica gel) must first be removed, access panels installed, and a **leak test (hydraulic)** performed.

If it is flooded with treated water for a wet preservation method, it is generally sufficient to lower the water level by purging it down and opening the **atmospheric valve** to break the vacuum (allowing air to enter).

FIREPLACE CRUSHED DUE TO APPARENT WATER LEVEL FAILURE



This failure of the firebox (crushing) occurs due to "lack of cooling," due to poor water circulation caused by various physical and chemical factors.

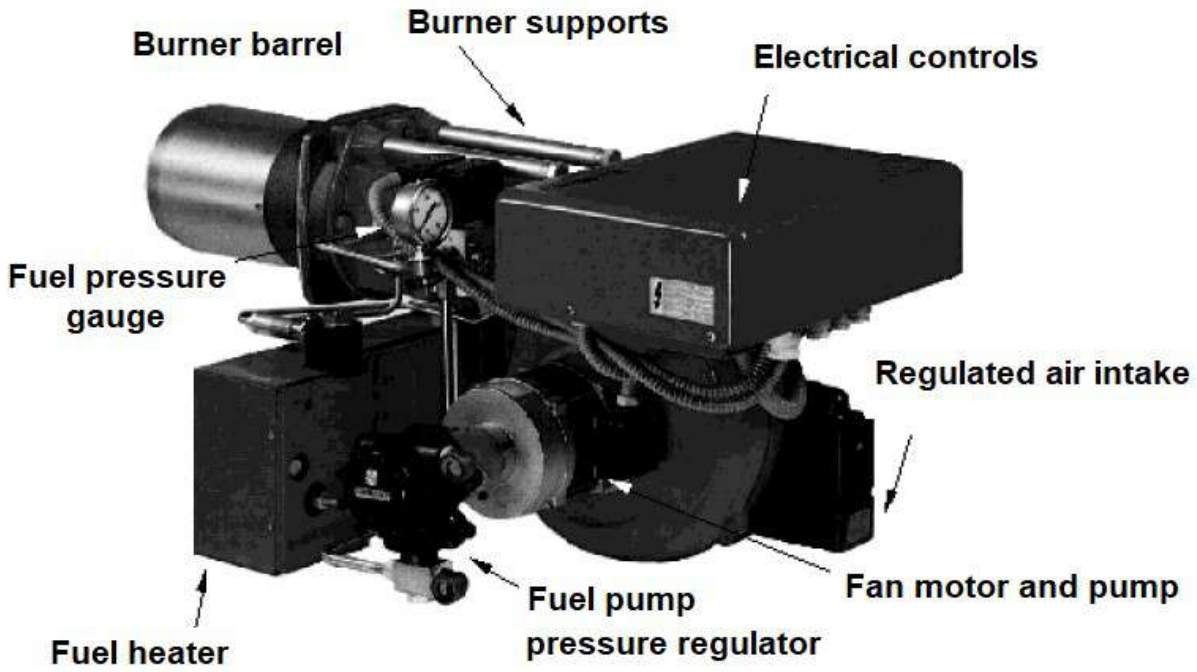
2- **Check the level controls switches** (open their purges and verify that they activate the **start/stop function of the feed pump** before opening its suction and discharge valves; listen and look for signs of low level).

In some cases, it is necessary to perform a **hydraulic "leak test"** (to check for water or steam leaks).

To do this, you can slowly build up the "working" pressure using the same **wáter feed pump**, venting the air through the **atmospheric valve** (the atmospheric valve serves both to vent air and gases and to prevent a "vacuum" from forming inside the boiler when cooling or emptying it).

After 10 minutes of pressure (with all valves closed), observe the exterior and interior of the boiler (firebox and smoke boxes) for water leaks, and ensure that the pressure on the gauge does not drop more than very slowly (this indicates a leak in the packing).

Then slowly release the pressure (purge) and adjust the boiler water level (opening and closing purge and atmospheric valve).



MECHANICALLY PRESSURIZED LIQUID FUEL BURNER

3- In Heavy Fuel Oil boilers (No. 6), check the fuel level in the service tank.

It is assumed that the fuel oil filters are clean and assembled.

Preheat with auxiliary heat (electric heating elements or auxiliary steam) to a pumpable temperature (40°C to 60°C) and do not attempt to pump without preheating (this can overload the pumps).

Then heat to the atomization temperature, which depends on the type of burner:

This can be: mechanical 120°C (248°F) to 145°C (293°F), steam and rotary cup 75°C (167°F) to 90°C (194°F), or low-pressure air 110°C (230°F) to 130°C (266°F).

These temperatures are approximate values; refer to the burner manufacturer. See heaters later in this chapter in the section dedicated to liquid fuels. Circulate the fuel oil slowly (taking care not to allow atomization) to ensure the system temperature and pressures normalize.

Next, before starting the burner, **check the induced draft** (or control openings in naturally draft chimneys), and **check the forced air** (primary and secondary air) by opening and closing their controls.

If the burner is automatic, it will perform the following steps automatically. However, if it is manual, proceed as follows:

a-No burner should be lit (nor its pilot light) before the combustion chamber has been "ventilated" (purged of combustible gases with clean air; otherwise, a combustion chamber explosion may occur).

The induced draft is fully opened, and the primary and secondary air valves are opened for a few seconds (90 seconds or more, until the combustion chamber and firebox are thoroughly purged of gases, **requiring at least four air changes**).

Then the primary and secondary air are closed to a "minimum" for starting and the induced draft until the depression (it is not always done under depression or vacuum: 3 to 5 mm.W.C. (Water Column): millimeters of water column, many boilers work with the furnace "pressurized", with pressure in the furnace chamber, which can reach quite high values) in the furnace is the running pressure (generally we should notice suction in the sight glasses or pilot burner inlet).

If the pilot light is gas-powered and fixed, light it. If it's a manual, hemp-made pilot light, light it outside and insert it through the ignition port into the firebox (slightly forward and to the side of the burner). Observing the pilot flame through the sight glass (from the side), very gently open the fuel oil regulator valve until you obtain a small but stable flame.

Some boilers must be lit with low-viscosity fuels: "Gas Oil" or "Heating Fuel Oil." For these, you must first install a smaller nozzle or igniter than normal. An auxiliary atomizing device (air instead of steam) may also be necessary.

Once the flame has stabilized by adjusting the fuel, forced air, and combustion chamber pressure (until the flame is a bright red and does not tend to go out or blow out), the pilot light is extinguished or the burner (wax) is removed.

While the boiler is hot, do not attempt to light the burner using residual heat or flames remaining in the combustion chamber refractories (this can cause serious combustion explosions). Instead, perform the procedure described above.

The boiler must be heated slowly until steam is released from the atmospheric valve (visible steam, not air), as **rapid heating can cause tubes to loosen in the mandrels, refractory material to loosen, or cracks to appear in the boiler structure.**

This is due to the material's expansion, which must be uniform, because heat tends to rise (due to convection in the water and air, the top of the boiler will be hot and the bottom will be cold, with each meter of the boiler potentially expanding by more than 2 mm).

Care must be taken to ensure that this low flame does not go out when the boiler is cold (as it tends to be unstable).

In automatic burners, purging, pilot light ignition (if needed), flame monitoring (photocell: shuts off the fuel supply when it detects a lack of flame, preventing the combustion chamber from flooding with fuel), and fuel temperature control are all performed automatically each time the burner is ignited.

It will even prevent ignition if it detects a flame or a luminous heat source in the combustion chamber (or very cold fuel, or in some cases, insufficient air).

Some burners allow you to select a **low flame setting**; it is advisable to preheat the boiler using a low flame.

Some burners will not activate the **high flame** until a certain steam pressure is reached (this allows for slow heating and protects the cooling of the hottest plate at low pressures or during high steam consumption that could cause the pressure to drop too low).

In automatic burners, the mechanism that controls the purging, ignition, and flame control sequences is called a **"programmer" (generally electronic or electrica**l, although some may have contacts actuated mechanically by a motor that drives a camshaft).

In both manual and automatic burners, when starting them, a large amount of fuel should not be allowed to enter without ignition.

If ignition does not occur (ignition within a few seconds), the fuel supply should be shut off and the attempt repeated (after purging and, if necessary, adjusting for drafts or pressure in the combustion chamber, and temperatures, to prevent flame blowout).

When the steam pressure reaches 1 to 2 kg/cm² (15 to 30 psi), it is advisable to operate the bottom valves to remove the sludge deposited on the bottom and test the bottom purge mechanism (ensuring the valves operate correctly and do not leak).

Then, gradually increase combustion by adding more fuel (either by increasing the fuel pressure or using larger fuel pellets, as needed) and increasing the air and draft. Maintain a medium flame until the operating pressure is reached.

Test the burner cut-off from the levels (by purging them),

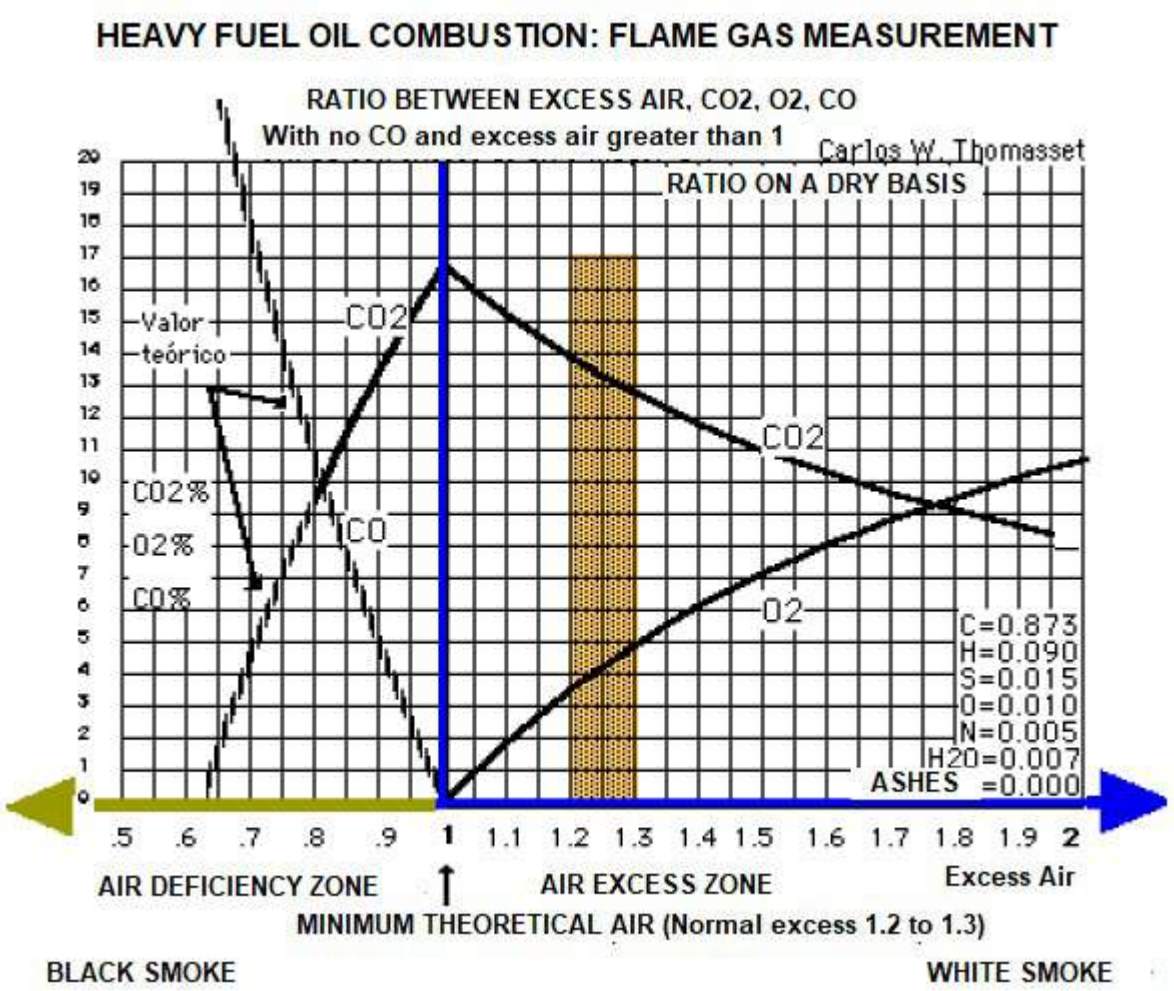
test for the lack of flame in the photoresistor cell (automatic burner all: remove the photocell and cover it from the light, the burner should turn off).

Once the system is secure and the boiler is steaming at the **working pressure,** slowly open the **steam outlet valve** (steam supply valve) (very slowly, or open a bypass in the case of high pressures or large valves).

Then fully open the valve (avoiding "scoring": scoring of the seat due to rolling: steam throttling).

Once the steam consumption is established, the water and fuel feed will need to be increased to maintain the balance of the water level inside the boiler and its steam pressure (which will tend to vary with consumption).

When the pressure drops due to **increased steam consumption**, we must increase combustion by increasing the amount of air and fuel in a related manner, and if the steam pressure increases, we must lower the combustion rate by lowering the fuel and air in the same ratio (air/fuel ratio).



Fuel Oil Combustion Regulation:

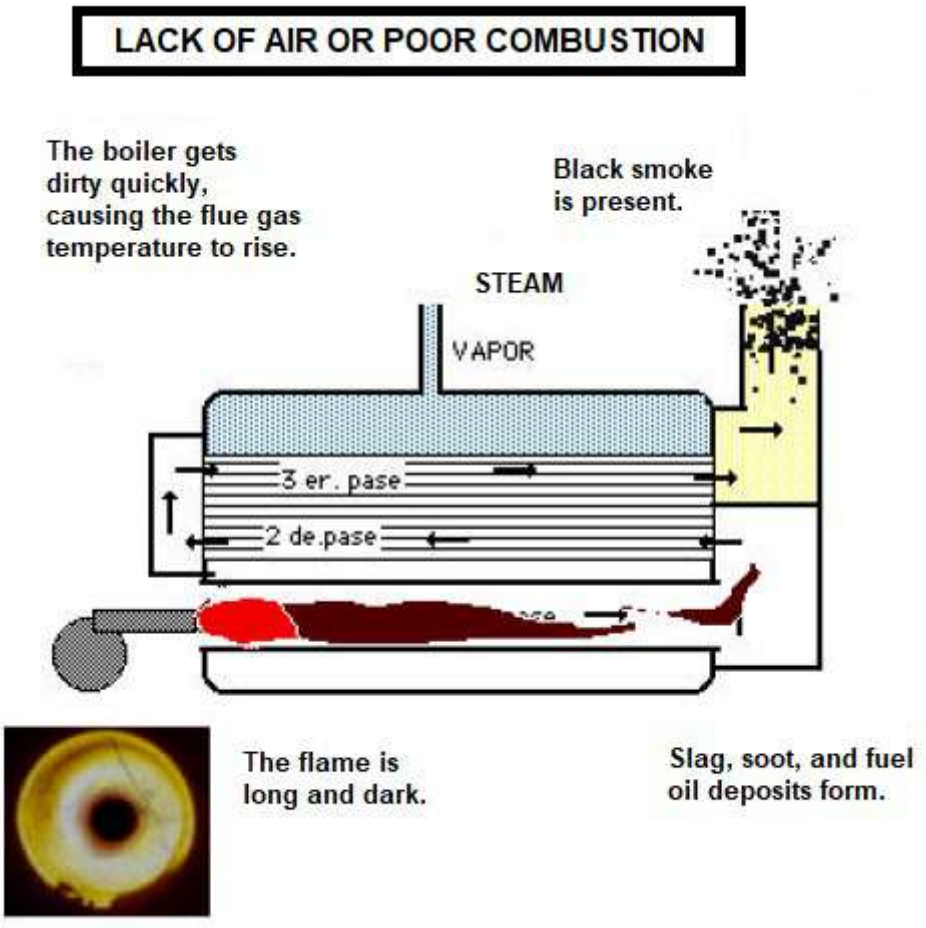
We have seen that for each kg of fuel, a certain minimum amount of air is required (more than 14 kg of air per kg of fuel oil), since we need an excess of air to achieve good combustion (free of smoke and soot).

This can be controlled using flue gas composition meters, but from a practical point of view, this is insufficient and such measuring equipment is not usually available. Therefore, we must judge combustion based on our visual observation.

We must observe the flame color and appearance: the color of the flue gases.

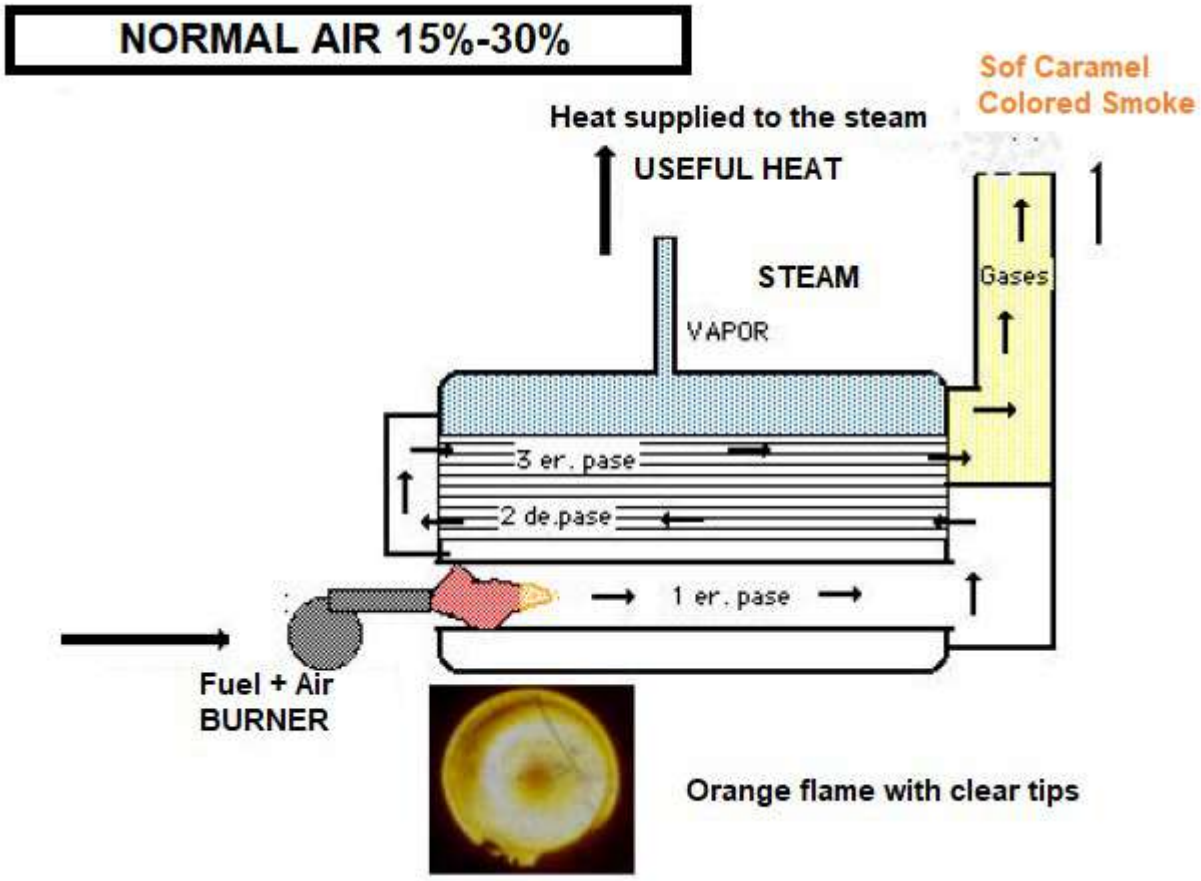
1-Lack of air:

the flame is dark red and long, there is black or dark brown smoke in the chimney (CO2 is more than 14% and O2 less than 3.5%, there may be CO and/or soot; CO may not form, but soot may. These values depend on the minimum excess air required for the type of burner).


LACK OF AIR OR POOR COMBUSTION
The boiler gets dirty quickly, causing the flue gas temperature to rise.
Black smoke is present.
STEAM
VAPOR
3 er. pase
2 de.pase
The flame is long and dark.
Slag, soot, and fuel oil deposits form.

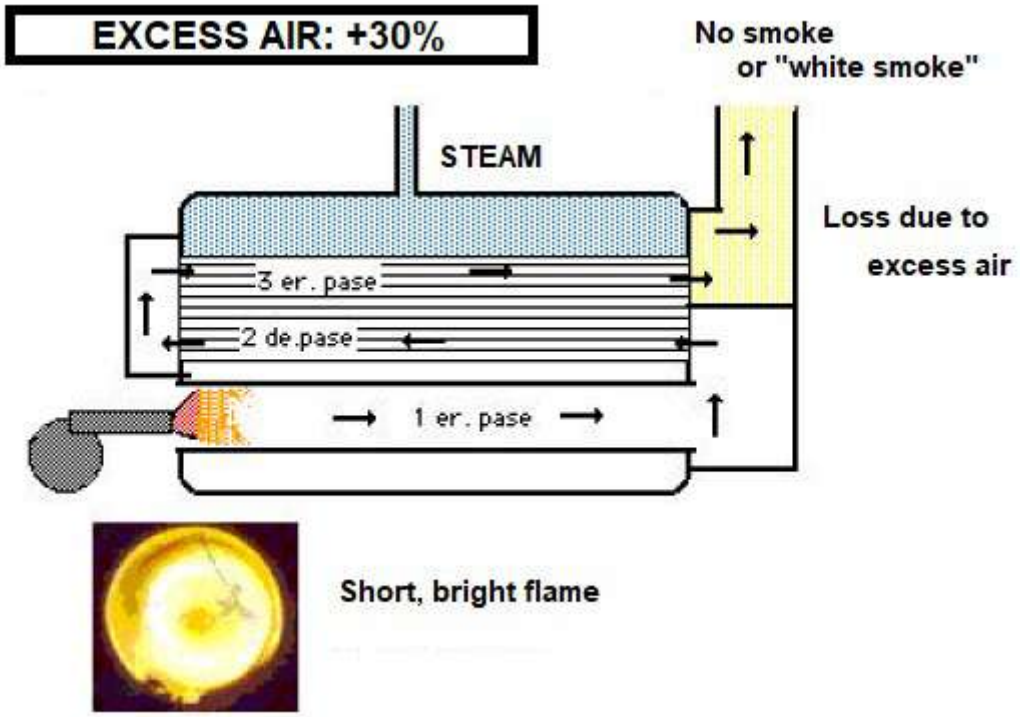
2-Good combustion:

The flame is relatively short and orange, and the fumes are only slightly perceptible (a light caramel color). CO2 levels will be between 12% and 14%, O2 between 3.5% and 6%, with no CO and almost no soot. These values depend on the type of burner and boiler.



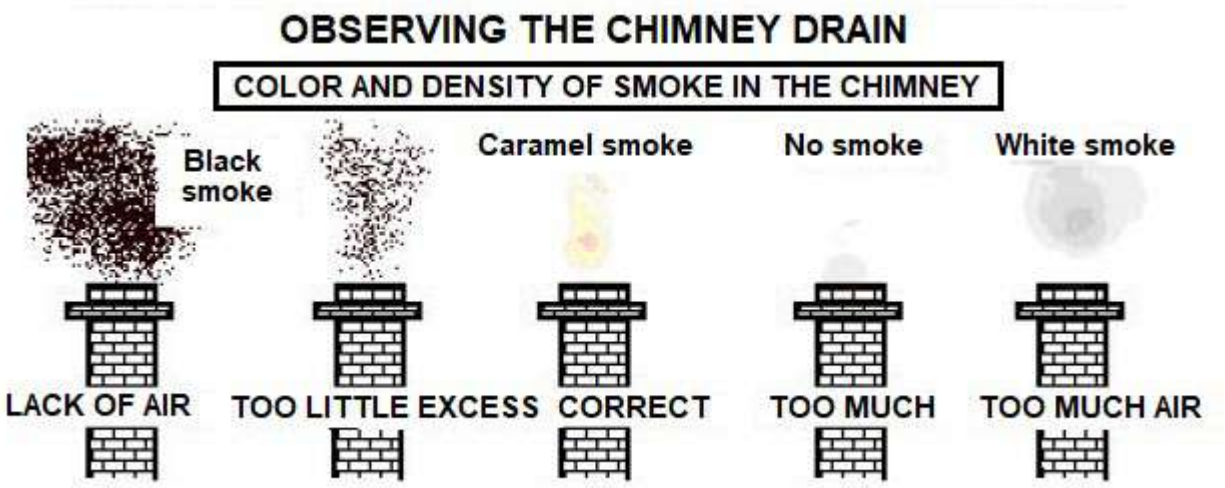
3-Excess air:

the flame is very short and a bright orange: almost white, no smoke is seen in the chimney or if the excess is very large the smoke is white. (CO2 less than 12%, O2 greater than 6%, depending on the type of burner and boiler).



4-Poor combustion:

There may be a lack of air or an excess of air in certain combustion areas due to poor atomization or poor regulation of the air-fuel interaction. Poor atomization, or fuel that is too cold or too hot (rotary cup), water in the fuel (spraying), etc.



The use of fuel additives promotes atomization in some cases (mechanical atomization, by lowering viscosity), but combustion problems must be corrected by adjusting the burner.

The use of additives generally emulsifies water (preventing water from settling in the fuel oil in the service tanks; if contamination is significant, this causes difficulties). Fuel additives can be designed to improve combustion by introducing incandescent particles into the flame (they contain salts that release particles which, upon contact with the flame, produce light and thus heat that accelerates combustion).

In other cases, their function is to neutralize sulfur and vanadium, or improve fuel circulation in the cold zone (filters and tanks, preventing or dissolving sludge from the decomposition of the fuel oil itself).

It must be clear that low flash point additives should not be used. The flash point is the temperature at which the fuel ignites momentarily in a container open to the atmosphere upon contact with a flame; the fire point is the temperature at which the fuel surface continues to burn for at least 5 seconds. This is dangerous because the formation of flammable vapors can cause an explosion in a home, tank, or building.

The flash point of fuel oil is approximately 65°C (149°F). It is generally heated for circulation to between 40°C (104°F) and 60°C (140°F), and then for atomization, the temperature will generally be no less than 100°C (212°F) and up to almost 145°C (293°F). This means that a low flash point additive is not suitable. (flash point) will produce explosive gases.

When purchasing additives, this is an important point to consider: the additive should have a flash point equal to or higher than that of the fuel.

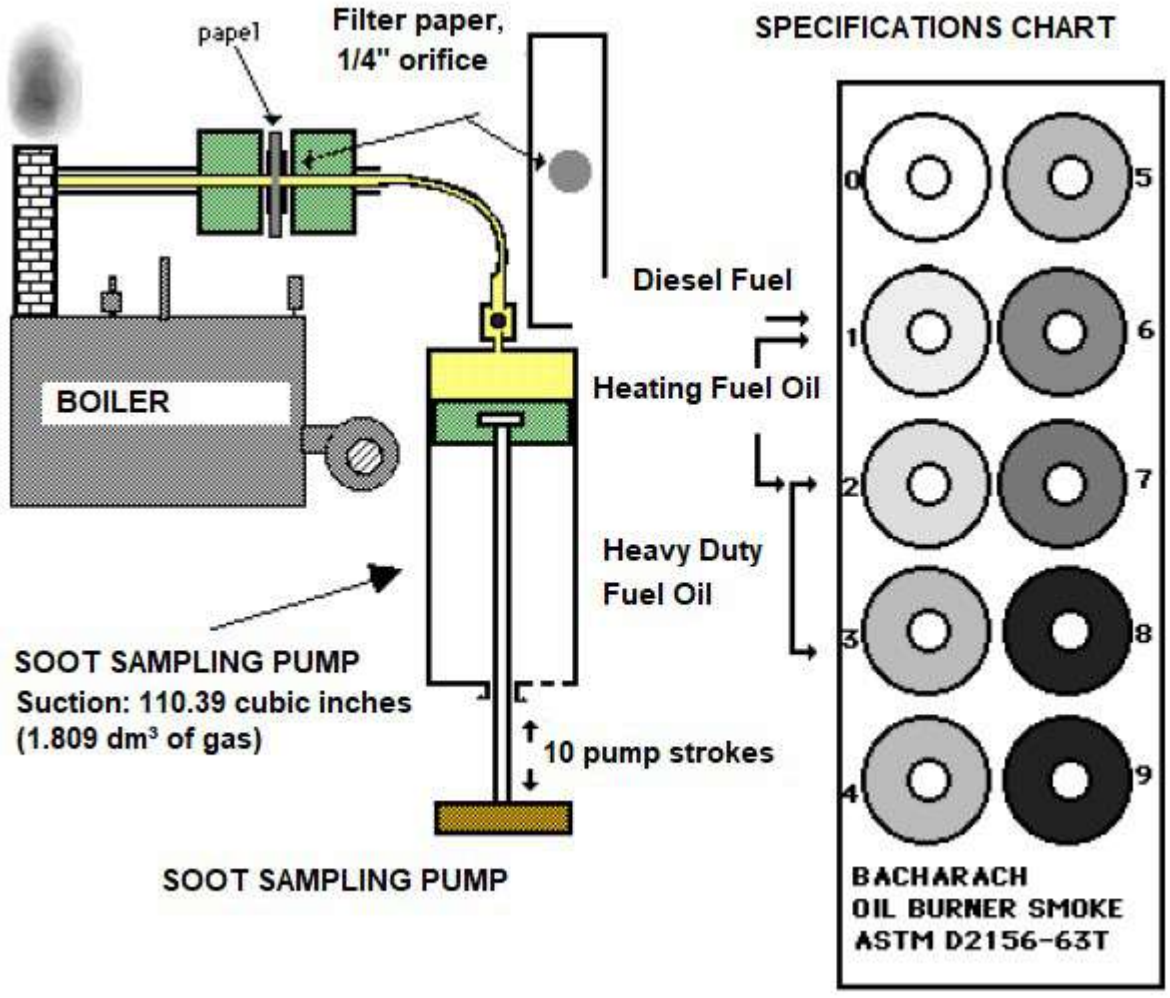
To monitor soot formation in flue gases, in addition to visual observation of the gases at the chimney outlet (which is an estimate), a soot sampling pump

such as the Bacharach can be used (which indicates soot levels in the gases more accurately than visual observation).

This follows the standards established by ASTM D2156-63T, which states that a soot stain on filter paper, caused by a flue gas volume of 110.39 cubic inches (1.809 dm³) passing through a 1/4" orifice (6.35 mm diameter), is compared to a chart with a corresponding soot number (these are circles with a soot-like color of varying shades, each with a 1/4" hole in the center through which the stain left on the filter paper is viewed for comparison).

For example: when burning Heavy Fuel Oil, the maximum acceptable soot level is #3, although with a burner in good condition, #1 can be achieved. For lighter liquid fuels, the maximum acceptable soot level is lower, as it is possible to work with very low soot formation, as in the case of Gas Oil, whose maximum level will be #1.

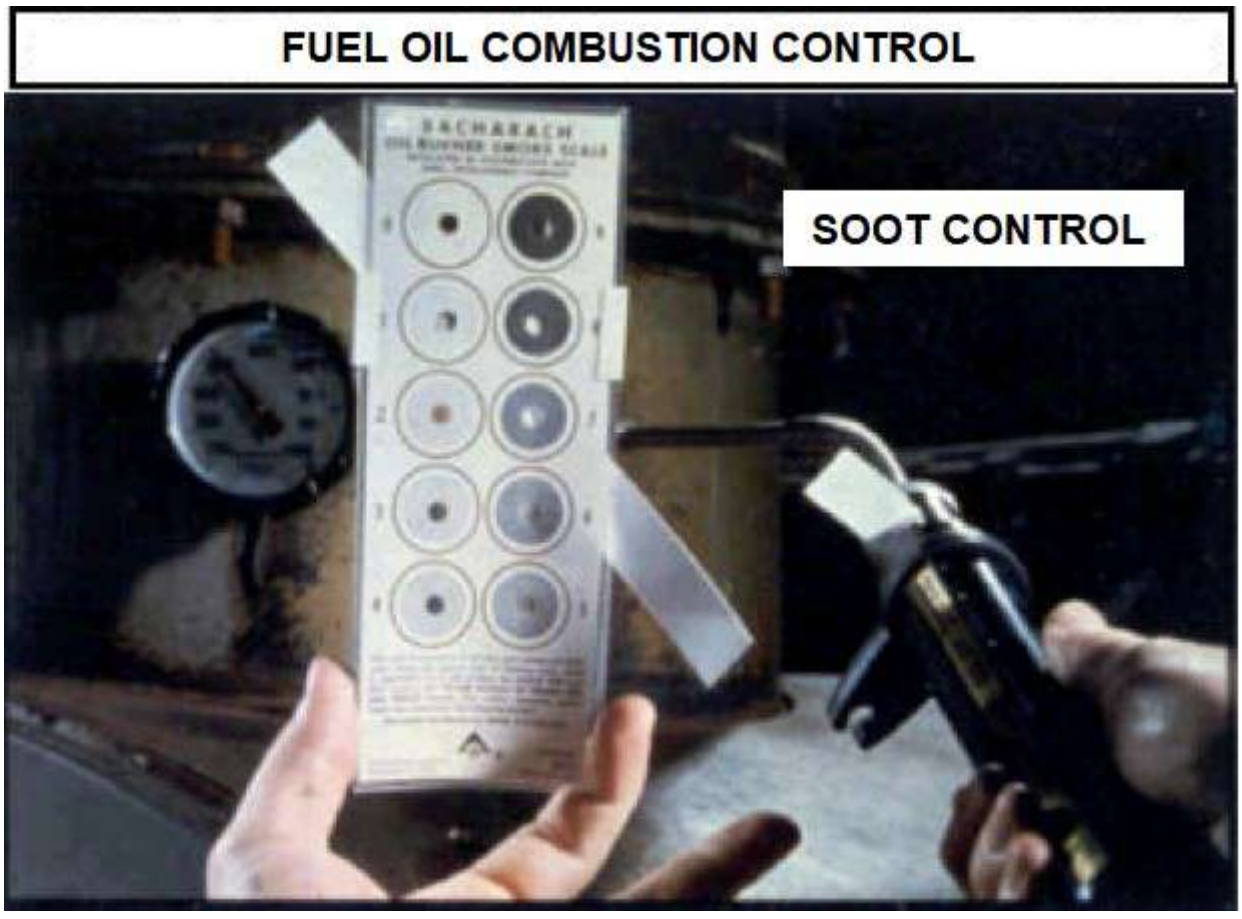
See the diagram below.



Excess air (CO_2 below 10% or O_2 above 5%) is not a sufficient indication that there will be no soot in the flue gases. Therefore, measurement with the Soot Sampling Pump (Bacharach®) is necessary, as incomplete combustion can occur for many reasons.

Simply observing flue gases is now completely insufficient. Generally, different fuel atomization methods mean that some work better with heavier fuels (such as atomization with steam or hot compressed air, and some "rotary cup" burners, which improve combustion of this otherwise difficult-to-burn fuel).

Of course, the operating cycle of a boiler also plays a role. A boiler with frequent starts and stops will produce significantly more soot because combustion is very unstable during the "start-up" period, leading to soot production until the flame stabilizes.



If the boiler shuts down due to a power outage or lack of water, close the steam valve (the burner will be off, but tubes may remain exposed to residual heat, without wáter level to cool them, if the steam valve is not closed).

When shutting down the boiler at the end of the day, the burner must be turned off (a post-purge of gases with air must be performed, since fuel may have leaked and formed explosive gases.

The steam valves must be shut off, the air vents must be closed, the fans and fuel pumps must be turned off (as well as the fuel heaters, the fuel control valve, the continuous purge valve, etc.), leaving the water supply running as long as there is steam pressure inside the boiler.

Do not force the pressure drop; the boiler will cool unevenly, creating harmful stresses.

After about 15 minutes of inactivity, it's advisable to perform a series of purges (as the sludge will tend to settle).

Once the pressure has dropped to almost zero, the boiler should be **flooded with treated water** (to prevent corrosion from oxygen in the air), leaving a water seal in place to compensate for the expansion and contraction of the water (in some cases, leaving the feed valve open is sufficient).

If the boiler is not flooded, a vacuum is created as it cools, which can cause reverse pressure stresses (atmospheric pressure). This must be taken into account in some types of boilers (as it can affect their structure, especially in low-pressure boilers) and can cause "suction" of products heated by the direct steam, contaminating the boiler water (digesters, vats, etc.) or the entry of oxygen, which causes corrosion ("pitting").

When the boiler is left in use for extended periods, the water conditions must be monitored to minimize corrosion.

To prevent corrosion, the water's pH must be above 10.5, and there must be sufficient chemicals to absorb (or combine with) any oxygen that may enter the boiler (even with the boiler flooded and with a water seal that allows for free expansion and contraction without atmospheric air entering).

Prevent steam from other boilers from entering the shut-down boiler (due to leaks in the steam valves), as the steam produces a corrosive condensate that affects the shut-down boiler.

The condensation at the top creates conditions that promote corrosion.

Under no circumstances should the boiler be left with a low steam level (consuming steam even with the burner off).

When the tubes are exposed, they are susceptible to corrosion. Therefore, in the event of a **power outage, immediately shut off the steam supply** to prevent the boiler from losing its normal steam level (thus avoiding corrosion and overheating of the tubes).

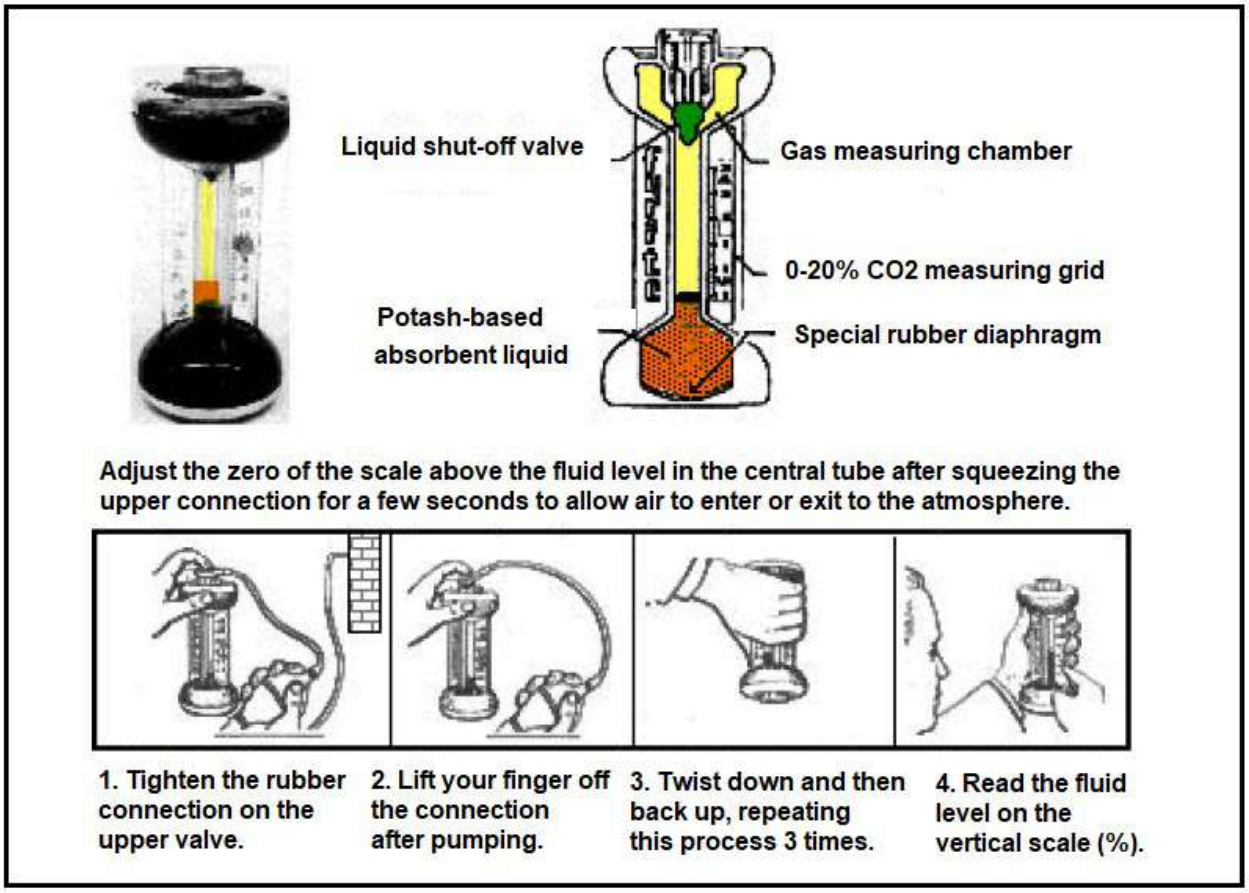
When the shutdown period exceeds several months and the boiler will not be used immediately, **"dry storage"** is recommended.

This involves draining the water, cleaning out the internal sludge with a hose, and completely drying the interior of the water and steam chamber (using hot air or electric heaters).

Maintain the interior dry during this period by using temperatures higher than ambient or by applying **moisture-absorbing products** (such as sealing the boiler with quicklime or silica gel). Periodically inspect the boiler and replenish the absorbents, taking care not to allow them to fall inside (lime is corrosive).

It is advisable to disconnect all pipes that could introduce water or moisture into the boiler (steam pipes, water supply lines, etc.).

Clean the soot-covered areas (by brushing, using compressed air, or with hot alkaline water) and dry them thoroughly (use heaters if necessary).


Liquid shut-off valve
Gas measuring chamber
0-20% CO2 measuring grid
Potash-based absorbent liquid
Special rubber diaphragm
Adjust the zero of the scale above the fluid level in the central tube after squeezing the upper connection for a few seconds to allow air to enter or exit to the atmosphere.
1. Tighten the rubber connection on the upper valve.
2. Lift your finger off the connection after pumping.
3. Twist down and then back up, repeating this process 3 times.
4. Read the fluid level on the vertical scale (%).

FYRITE EQUIPMENT FOR MEASURING CO2 AND O2 IN BOILERS

The FYRITE (Bacharach) is a chemical absorption device for measuring CO2; similar devices exist for O2.

In the case of CO2 (carbon dioxide), potassium hydroxide (KOH) is used as the absorbent at a specific concentration (it absorbs the sum of CO2 and SO2, with the SO2 content generally being very low).

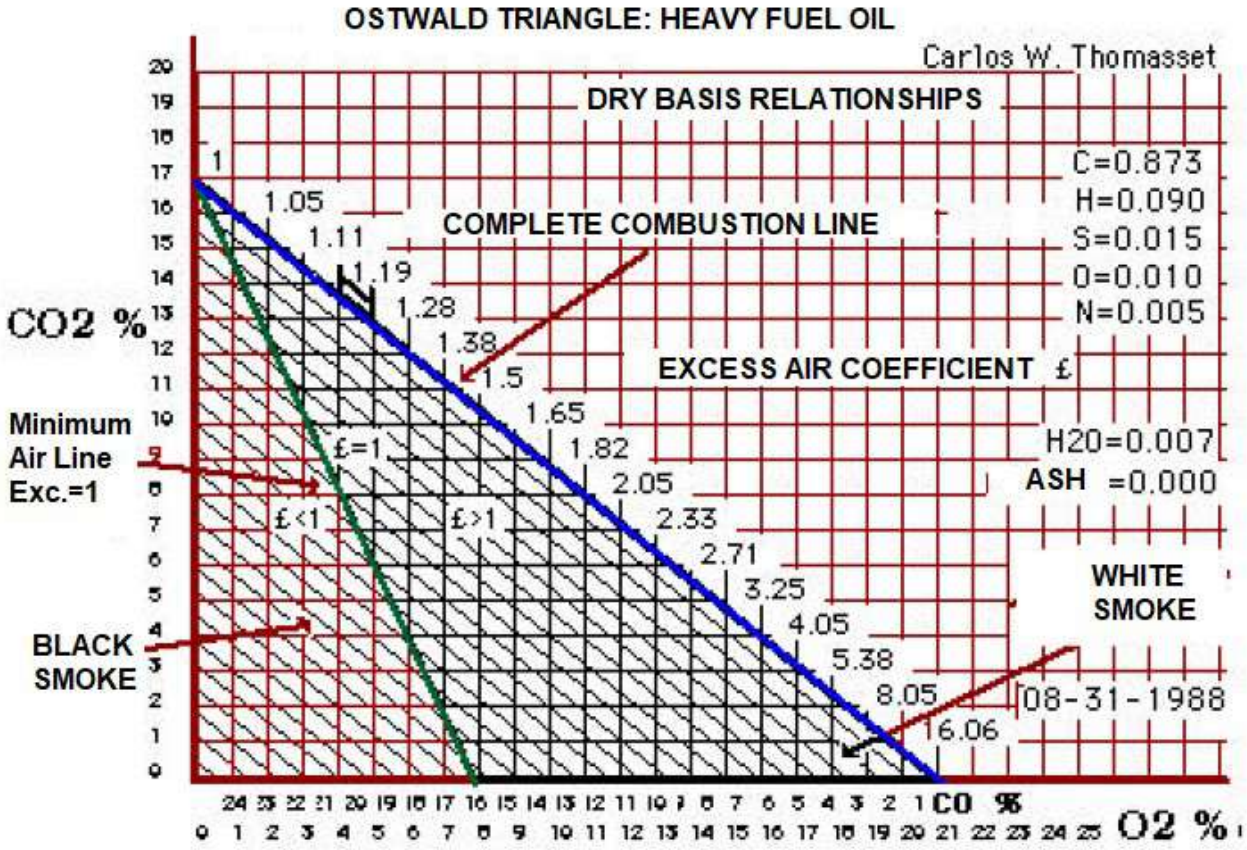
The measurement is taken in a hydraulic column (a tube containing gas and liquid) that is subjected to the weight and pressure of the solution as it absorbs CO2. A membrane at the bottom of the liquid chamber also absorbs atmospheric pressure (after calibration to 0% by opening the device to the atmosphere and then adjusting the scale to zero).

Once the sampled gas trapped in the upper chamber is mixed with the potash, the CO2 is chemically absorbed, which lowers the internal pressure. Atmospheric pressure then pushes the diaphragm to equilibrium. Reading the level that rises in the vertical central tube at this point will give the CO2% reading.

The O2 meter operates similarly, although the absorbent is a different selective chemical, meaning it only reacts with O2. (The problem with the O2 meter is that any air intrusion, when the equipment is at rest or stored, will deplete the liquid, something that doesn't happen with the potash.)

These devices have the great advantage of simplicity and ease of maintenance (or repair); their error, although it can be up to 0.5%, is sufficiently precise for adjusting combustion in the most common boilers.

Remember that these devices measure gases in dry relation (considering water in the flue gases as absent, i.e., condensed).



It must be considered that each Ostwald Triangle, as well as the theoretical flue gas curves, are plotted with values of the % of gas on a "dry basis" (and depend on the composition of the fuel and the air at sea level). That is, it is considered that the water that the fuel brings plus the water produced by the hydrogen contained in the fuel is considered as if it were "condensed" or transformed into water by cooling (it does not exist as if it were another gas, like CO2, O2, CO, N and other gases if there is poor combustion).

Therefore, when using an instrument to measure gases, we must understand its operating principle. If it measures "hot" gases, the water vapor in the flue gases will affect the measurement (as is the case with zirconium oxide cells for measuring oxygen). Other instruments cool the gases to ambient temperature, but some evaporated water remains, slightly influencing the percentage reading.

Orsat, Fyrite, and other absorption instruments measure on a "dry basis." While the water vapor condenses, the small amount that remains is "compensated" in the measurement.

HEAVY FUEL OIL HEATERS and their problems:

The use of heavy fuel oil (also for heating fuel oil, that is, heavy fuel oil whose viscosity has been reduced by adding diesel oil by almost 30%, which facilitates pumping at low temperatures and then, during atomization, must be used at a lower temperature than required for heavy fuel oil, allowing it to be used in smaller burners whose atomizing nozzles cannot properly atomize the heavy fuel oil).

The preheating of heavy fuel oil for pumping is generally done in storage tanks using steam coils (whose condensate should be discarded in case of contamination if one of the coils is punctured). The preheating is done to a temperature at which it can be pumped without problems (an excessive temperature can be counterproductive for the operation of the pumps and even for their sealing in the packings).

This temperature is generally around 50°C 122°F (the heat required to raise the temperature of 1 kg of fuel oil by 1°C, called specific heat, is approximately 0.5 kcal/kg or 0.9 BTU/lb, that is, half the amount required to raise the temperature of 1 kg or 1 liter of water to the same temperature).

Given the pumping distances, both supply and return, it is necessary to have the pipes insulated and also with heating elements (steam or hot water tracers, as well as electric ones, these elements are in contact with the metal of the F. Heavy Oil pipe and transmit a certain temperature to keep the fuel in the vicinity of 50ºC 122°F).

Steam or hot water heat tracer systems are simple iron or copper pipes in contact with the fuel line and connected to it by means of "heat bridges," always beneath the insulation.

In electrical tracers, there is a very interesting variety, from a simple cable with a "resistive" effect that, when a current passes through it, heats up like a stove, to elements with cables that actually operate at very low voltage and high current, causing a heating effect through the alternating magnetic field in the fuel line (the latter is widely used in oil pipelines that transport fuel through cold regions and over long distances, such as in Alaska, Canada, etc., although it can also be used in boiler systems).

When these tracers are not available, in smaller installations, there are two ways to start pumping the cold fuel:
1.- Stop the boiler using a lighter fuel such as heating oil or diesel or gas oil,
2.- Heat all the pipes with a gas torch before attempting to start the heavy fuel oil circulation pumps.

In the boiler room, fuel can be:

a- drawn by the burner's fuel pump (under negative pressure);

b- taken from a "low-pressure fuel ring," that is, a supply and return piping system to the fuel tank;

c- drawn from an elevated service tank (under pressure—higher than the pump, which presents significant problems in the event of fires, especially due to spills);

d- drawn by the pump from a sealed cylinder (pressurized towards the pump, providing fuel for a few minutes, but with the significant advantage of being sealed against spills).

I have found this last system to be very simple and very safe, provided it is properly designed. It is similar to the ring system but has the advantage of better managing fuel pressure fluctuations when pumping conditions change.

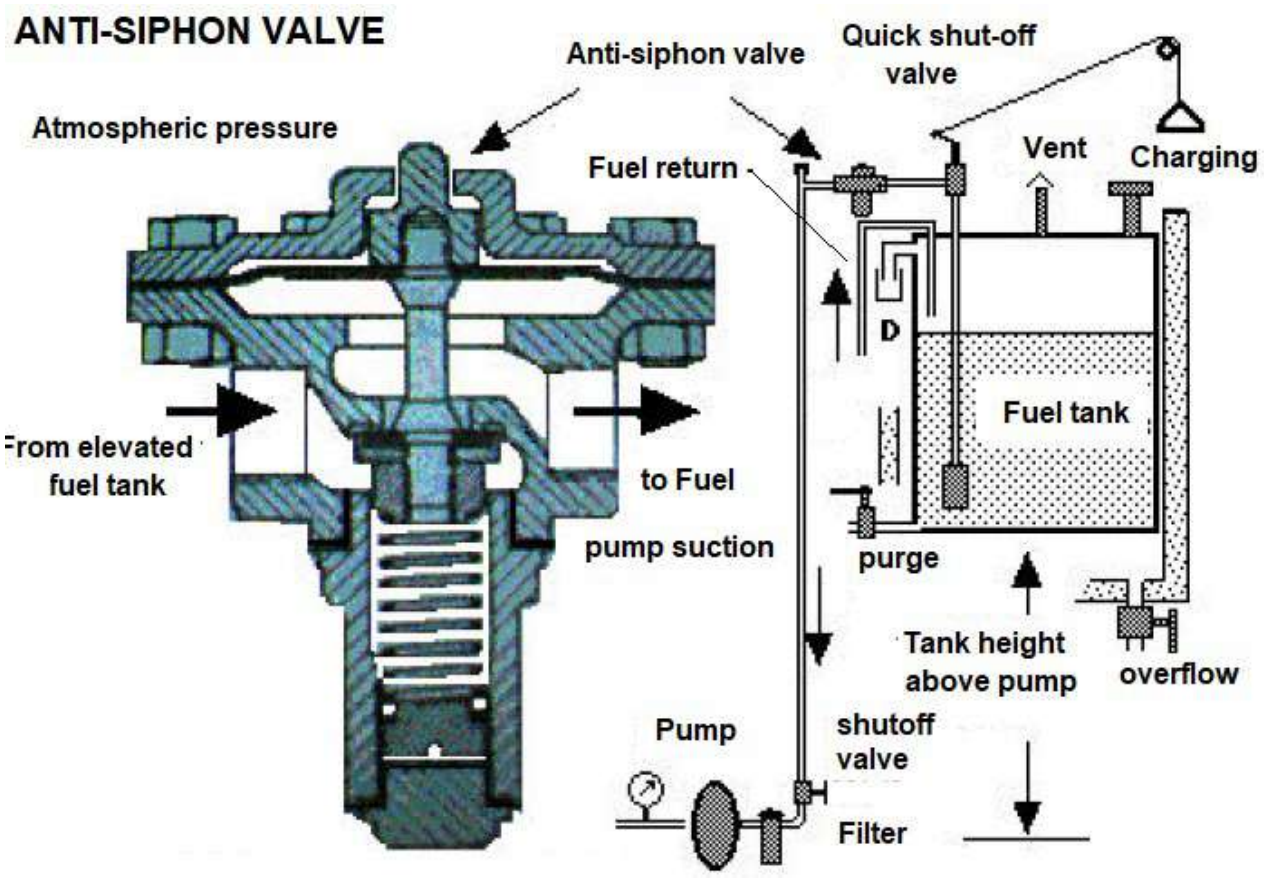
CHAPTER 5: Operation Part 2

ANTI-SIPHON VALVE

The risk with light fuels (diesel, diesel oil, and even highly heated fuel oil, etc.), when there is an elevated service tank, is spillage due to a lost connection, a broken pipe, or a hose.

To prevent this, anti-siphon devices are installed; that is, devices that prevent spillage due to gravity.

These siphons can be of the static type (pipes), solenoid valves, or dynamic type with anti-siphon valves. Let's look at an example of the latter:



Among the installation errors in fuel systems is the placement of a valve in the fuel return pipe: in this case, if someone closes it by mistake, the burner hose will "burst" due to excess pressure when the burner pump is turned on (if a valve is necessary, it is advisable to install a check valve or a valve with a "by-pass" and a relief valve).

THE FUEL TANK:

The problem of fire must be considered a priority.

Depending on whether it is light fuel (Gas Oil, Diesel Oil, or Heating Oil) or heavy fuel (Heavy Fuel Oil, or No. 6 or Residual Fuel Oil, etc.), the appropriate accessories and tank design will vary.

For lighter fuels, the previous figure represents the case of a tank elevated above the burner (here, the problem of spillage due to siphoning or simple gravity must be considered by installing an anti-siphon valve, or a solenoid that activates only when the burner is lit, enabling suction from the tank, or a piping system that prevents the siphoning effect, creating an artificial "air chamber" in the suction line, so that the pump remains in suction if a rupture occurs in the hoses or pipes near the burner).

The spill containment tank in case of a rupture or overflow is not fully depicted in the previous tank diagram. Therefore, a lower tank with a larger capacity is required to receive the fuel in the event of a puncture or overflow.

These tanks are very sensitive to fuel "refilling," as they require both an automatic control system and a visual system for monitoring the maximum and minimum levels, along with a system for overflow (which should occur in a designated area).

The automatic level control systems must be appropriate, as the fuel has very low conductivity. Float systems suitable for the fuel and capable of withstanding the operating conditions are preferred.

There must always be adequate venting (outside the room), **a spill containment container in case of a tank puncture, and a designated area for containing any spilled fuel.** The tank's bottom drain should be located below the suction line (which must have a filter before the pump) to remove settled water.

However, when dealing with heavy fuel oil, the tank must have a heating system for pumping (since heavy fuel oil, when its temperature is below 30°C (86°F) to 40°C (104°F), is almost impossible to pump due to its high viscosity).

The **heating system** (generally steam or hot water) must be located in the suction area of the transfer pump or the burner itself.

The suction foot or suction valve must have a **check valve** (which prevents the pipeline from losing its prime when under vacuum or with pressure dropping into the tank). This valve must have a seat with good sealing characteristics, such as Viton, which resists chemical attack and remains supple.
Furthermore, it must be protected by a **filter** made of an inert material that is not affected by the chemical properties of the water in the fuel, such as a **stainless steel mesh**.

It's always advisable to have both low and high fuel inlets. The high inlets can be used when working to avoid drawing in water, while the low inlets can be used when fuel is low. The inlets should be removable for maintenance, and each should have a top connection for priming whenever they are emptied for any reason.

These **heavy fuel oil tanks**, while they can be **above ground** (with an extra containment container in case the fuel spills due to a tank rupture), can also be **"underground",** but they must also **have an external sealed container for leaks or tank ruptures (so as not to contaminate the subsoil), and there must be a way to take samples from the bottom of this containment to see if there are any spills.**

All tanks, especially those for heavy fuel oil, must be properly insulated, even those for light fuels if they are exposed to the elements (as this would affect combustion by atomizing a very cold fuel).

Heavy fuel oil needs to be heated in the tank or kept warm at approximately 50°C (122°F), the temperature it usually receives from the ship or truck, so insulation prevents energy loss.

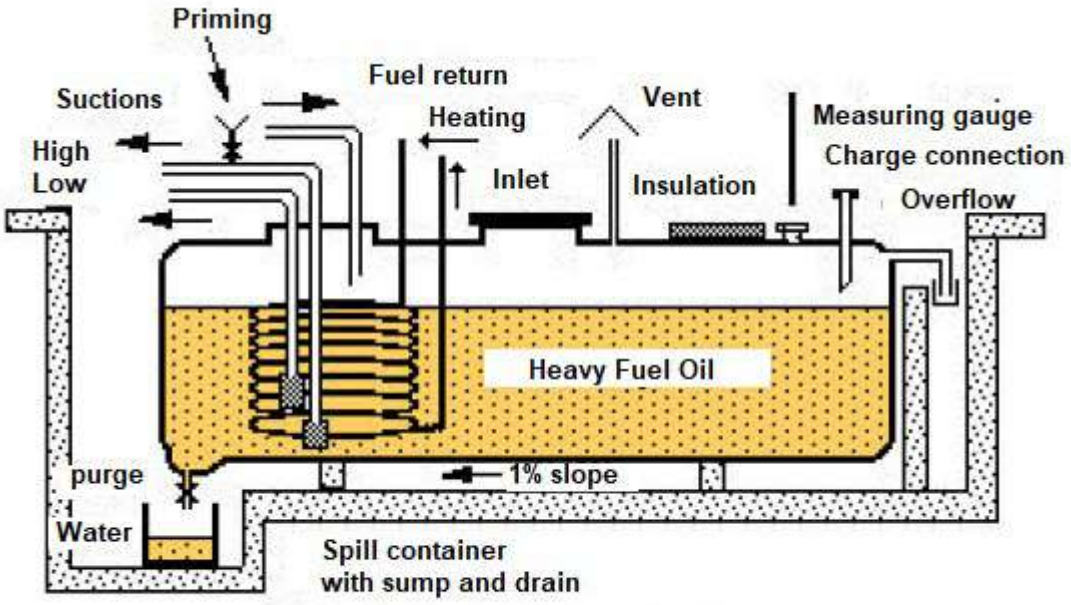
With heating fuel oil, even at ambient temperature, pumping problems from the tank to the burner can occur in cold weather.

It is very important to understand that with underground tanks, even if they have two tanks, the problem of corrosion persists. Even if the tank is painted, the presence of water or moisture in any pores on the protective paint surface will cause galvanic pitting, which will eventually perforate the tank within a few years.

To prevent this, the tank should be kept on a dry surface, usually sand, and **sacrificial anodes** (generally aluminum) can be installed. These anodes are connected to the tank and buried in the sand.

There can also be **corrosion inside the tank**, hence the importance of tilting the bottom of the tank towards the drain, in order to properly remove the water that comes with the fuel.

It is very important that the tank is "secured" to prevent "buoyancy", that is, with the tank empty, it can float because the safety tank or spill containment basin fills with water; therefore, the securing is important, since for every m3 of tank capacity, there will be 1,000 kg of buoyant force, minus the weight of the tank. **This buoyancy can break the connections or cause the tank to rotate, which is the same damage.**



BASIC SKETCH OF HEAVY FUEL OIL TANK

The Service Tank (F. Oil)

A service tank is not always necessary. A service tank is useful when the storage and receiving tanks are located far from the pumps or burner suction lines, since a "depression" in the suction line with a heavy fuel makes pumping difficult (due to viscosity, the possible entry of air due to the pressure drop, small diameter piping, etc.).

Although the implementation of this tank presents several risks: the risk of fire, level control for fuel refilling (it can be automatic, but overflows

occur if the automatic system fails; the overflow must be directed to a safe recovery area), and the fact that **the fuel must be heated** (at around 50°C/122°F, fuel vapors are produced, which are harmful to health and can cause an explosion if near an open flame or an electrical short circuit).

Furthermore, it requires **extra heating for cold starts**, and the fuel has high viscosity. There are also the problems of **purging accumulated water** due to settling (water separates more easily with slightly warmed fuel) and the release of gases or air drawn in by the burner pumps and returning to the service tank.

But the biggest problem is fuel spillage in the boiler room (there must be a lower container capable of receiving all the lost fuel, almost impossible if the transfer pump is still running).

To avoid this, a sealed, well-walled metal intermediate tank can be built with a **fuel reservoir for a few minutes to an hour of operation.** The fuel is pumped from this tank by a pump located near the main tank when the burner is in service, and any excess fuel is returned to the same tank.

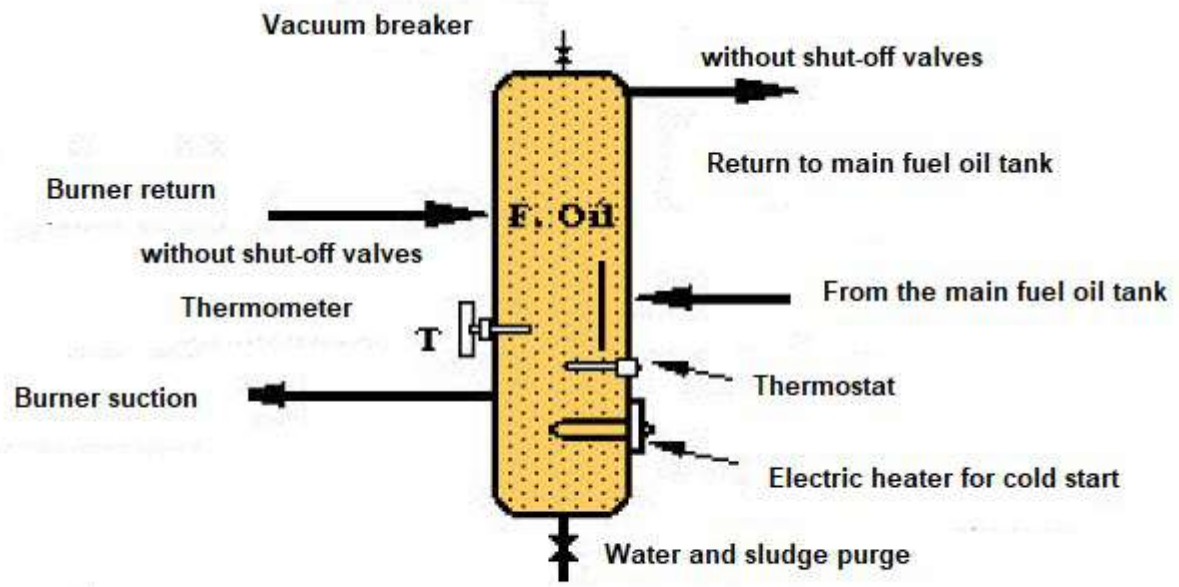
This reservoir is pressurized for the burner pumps by its installation height above the burners and by the pressure loss in the return pipe (the return line is located at the top and returns to the main tank; all these pipes are of a good diameter, no less than 1 1/2" (for heavy fuels), insulated, and fitted with heating tracers, carrying away the gases and air, which then go to the main tank's vent).

The burner feed is at an intermediate height to avoid drawing in sludge and water from the bottom of the reservoir, with the purge valve located at the bottom.

The burner return line is located closer to the reservoir return line to separate the gases at the top. The fuel inlet from the tank has a **baffle** to separate gases, air, and water without creating a direct suction to the burners.

This tank must never be subjected to the pressure of the fuel pumps (i.e., if it has a valve on the return line to the main tank, it must have a relief valve in parallel with that shut-off valve).

When constructed, it **must withstand the working pressure without problems** (perform a hydraulic test). With very cold fuel, it may reach a higher pressure due to the effect of viscosity in the return line (therefore, the return line must be of generous diameter, insulated, and heated).



SEALED INTERMEDIATE FUEL TANK

THE FUEL HEATER IN THE BOILER

Next, the temperature must be raised for atomization, depending on the type of burner used. This will be achieved using either steam or electric heaters.

Steam heaters are generally of the vessel type, which may contain a steam coil, steam tubes, plates, and tubes (with a system to absorb the expansion of the body relative to the tubes located between the plates).

The most significant issue here is that the heater body may be subjected to the pressure of the atomization pumps (to prevent the pumps from being subjected to high temperatures, which causes rapid wear and tear and makes it difficult to maintain their efficiency) or to the low pressure of a low-pressure ring and the high-pressure pumps (which are subjected to high temperatures).

Since the **pumps are generally positive displacement** (that is, if their discharge is closed they raise the pressure to the mechanical limit of the system, as if it were a "screw"), this forces the pump and the heat exchanger body to have a relief valve system, in case someone closes the heater's discharge.

The other problem is the hydraulic expansion of the fuel (if we confine a liquid in an iron container and heat it, without any air or gas bubbles inside, the

pressure can rise to the point where the container breaks or stretches, since the liquid will expand more than the container).

Therefore, if someone closes the fuel inlet and outlet valves and then applies heat, without a relief valve, the heater is very likely to malfunction (with or without risk to people; remember that fuel oil is generally hot, exceeding 100°C/212°F).

If the steam control thermostat is located in the heater itself, this overheating can be avoided (provided the solenoid or thermostatic control valve is not lost, which would cause the temperature to rise to the maximum temperature of the feed steam to the heater), but expansion will still occur because the fuel entered at a low temperature and rose to the operating temperature.

If the thermostat is located outside the heater, in the outlet circuit, the temperature will be even higher, and so will the risk. We must ensure there is a relief valve.

There are several types of steam heaters with a vessel. In all of them, the problem of the difference in expansion between the vessel body and the tubes is generally taken into account. The tubes, being in contact with the hotter steam, will expand more than the vessel itself.

The steam will be controlled by a thermostat that will activate a solenoid valve or a thermoregulating valve. Generally, the condensate will be discarded to prevent contamination of the boiler feedwater. The condensate will be controlled by a steam trap, which, being a float trap, will only allow condensate to pass through, with very little steam loss (thermodynamic traps consume steam to operate).

It is advisable to frequently check the appearance of the condensate for fuel oil leaks, as there is a high risk of contaminating the boiler water with fuel oil (which is very harmful) when the fuel pump is turned on, which raises fuel pressure in the heater.

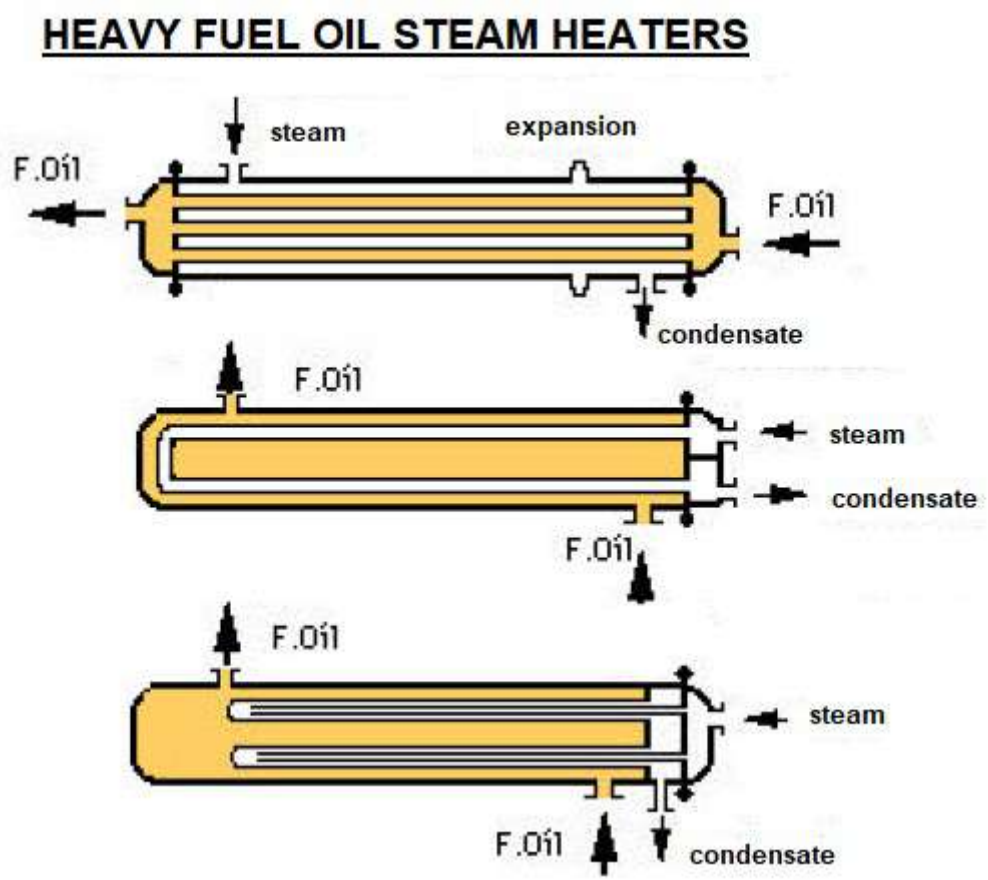
This occurs when the boiler's steam pressure is lower than the fuel pressure inside the heater. **When contamination occurs, a "halo" appears floating on the water in the visual level tube, or the fuel itself may be visible in the level tube.** This can cause boiler water carryover, odor in the steam, or worse, burn out a tube due to lack of heat transfer.

To prevent fuel from entering the boiler through leaks from the heater, it is advisable to install a check valve in the steam supply to the heater (perhaps with a Teflon seat to ensure a good seal), a valve that will be connected after the steam regulation system, in an area where its effectiveness can be checked.

Sometimes, annual cleaning of the fuel-side heater is advisable to remove carbon deposits that impede efficient heat transfer. This can be done mechanically with a turbine system (sometimes preceded by a chemical treatment using hot trisodium phosphate circulated for several hours on the fuel side of the heater with an external pump, ensuring this solution does not enter the fuel system).

Heater corrosion typically occurs on the steam side, in the condensate collection area.

Therefore, the heater should have condensate extraction at the lowest point of the steam chamber to prevent condensate from accumulating, especially when the heater is shut down (when the steam is cold or closed and air is allowed to enter).



In **auxiliary or main electric heaters**, if the system is based on a vessel with internal heating elements, the problem is exacerbated.

Since electric heating elements reach high temperatures, if there is no heat dissipation, this temperature will increase (in a steam heater, the maximum temperature will be that of the saturated steam in the boiler itself, and the maximum temperature that the fuel oil can reach, while not ideal, will not be as high as with electric resistance heating).

There are several aspects to consider here:

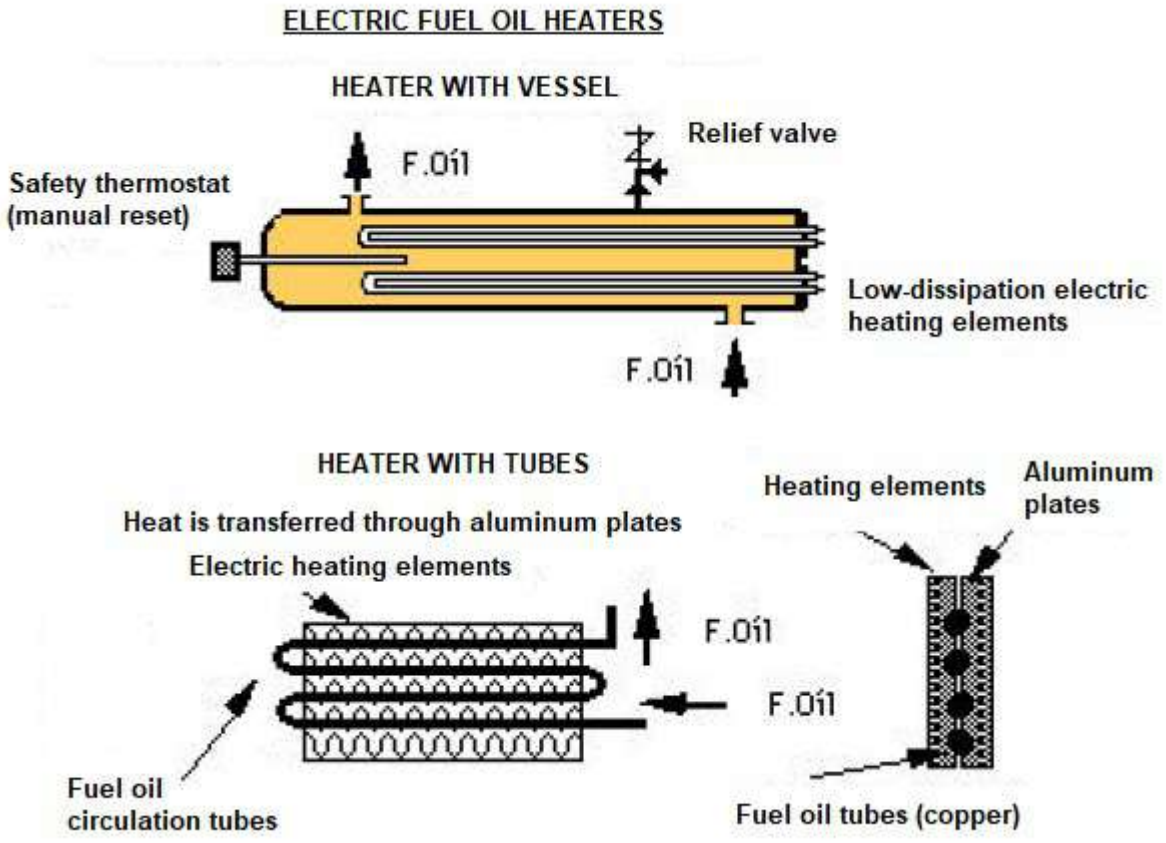
1.- **A high-temperature thermostat must be installed within the electric heater itself to prevent dangerous overheating.** This thermostat should cut off slightly above the operating thermostat and be of the manual reset type, meaning that once it trips, it must be manually reset to alert the boiler operator of the problem.

This high temperature not only burns the fuel oil or the heating elements but can also produce high pressures if the system lacks a relief valve, potentially causing the heater to explode.

This high-temperature thermostat between the heating elements also protects them if the heater is ignited without fuel circulation. If this were to happen, the elements would burn out due to lack of heat dissipation.

2.- **It must have a relief system to absorb the hydraulic expansion of the heating** in case it is not connected to the fuel system (and also in case the high thermostat fails or the contactor gets "stuck", causing the temperature to rise with the heater not connected),

3.-**The resistors must be suitable for heating viscous liquids** (the dissipation with area cm2, **must be low enough so that it does not burn the resistors and does not burn the F. Oil, making "scales" that will wear out the pumps**, the atomizing nozzles or block some solenoid or relief valve duct- Generally this dissipation is much lower than the common resistors used for heating water such as in water heaters, in the order of 3 to 5 watts/cm2).



In some electric fuel heating systems, to avoid risks such as fuel burning due to lack of circulation and excessive heat dissipation by the electric heating elements, the heaters are made of tubes through which the fuel circulates. These tubes are immersed in a heat-conducting metal mass, which is heated by electric heating elements.

In any case, there is an extra, non-externally adjustable safety thermostat that conveniently has a manual reset; that is, once it trips, it must be "reset" by the operator (so that they are aware of the situation.

When a fuel is heated above the recommended atomization temperature (to achieve complete combustion), the problem is generally due to a malfunction of the burner system (it is not advisable to heat heavy fuel oil above 155ºC (311°F), since from that temperature onwards, problems begin to arise due to the formation of fuel "scald" which causes various problems in the system: wear, blockages of filters, ducts, solenoids, etc.).

Do not attempt to troubleshoot burner adjustment problems by overheating the fuel.

Regarding the cost-effectiveness of heating fuel oil, it's important to note that some of the energy supplied to the fuel as heat to lower its viscosity and

achieve good atomization is added to the heat released by the fuel itself. **However, the most significant factor is the energy source used for this heating: electrical energy is clearly the most expensive (while using the boiler's own steam is the most economical).**

The specific heat of fuel oil (Cp: approx. 0.5 kcal/kg/°C, heat required to raise 1 kg of fuel by 1°C) is half that of water. If we use steam, for every 1 kg of steam, we can heat 10 to 11 kg of fuel (to over 100°C).

If we use electricity, for every 1 kWh (860 kcal/kWh), we can heat about 17 kg of fuel under the same conditions. However, to generate 1 kg of steam, generally only about 0.070 kg of fuel oil will be sufficient.

This shows how much more economical it is to heat fuel with steam (since, to equate heat, approximately 0.120 kg of fuel oil will be sufficient for every 1 kWh of combustion in a boiler with a 0.85% Total Efficiency at LHV).

Fuel contamination problem:

The most common fuel contamination is water, which can enter the fuel tank through seepage, rainwater, condensation, or leaks from heating coils (although there can be other types of contaminants, from sand to the mistake of "pouring" cleaning solvents or simply used oils into the tanks, which will later make the situation very dangerous due to the volatility of these components).

When the water content in fuel is very low (less than 1%), and the emulsion is good, it improves combustion quality (there is an improvement in atomization; in fact, there are machines that can emulsify water up to 3%).

However, when the percentage of water exceeds a certain limit, "sparks" begin to appear in the atomization cone, until a point is reached where combustion becomes unstable and the burner shuts down.

When using fuel additives, the problem is that water is very difficult to remove by "decantation," since fuel additives tend to emulsify the water contamination with the fuel.

Therefore, it is not advisable to add fuel additives if the tank is prone to water penetration and needs to be removed as such.

Another factor that makes water extraction difficult is the **density of heavy fuel** oil when it reaches 1 (1 liter = 1 kg).

If this happens, the water doesn't separate from the fuel and sinks to the bottom (water pools form at any height in the tank).

To separate the water in this case, **there's no other option than to mix this heavy fuel with a lighter fuel** (heating fuel oil, diesel, or gas oil) in a percentage that lowers the density to less than 0.98 (after thorough mixing, sometimes by gently heating the fuel and then letting it rest for several hours, the water will settle).

As for other types of contamination, each case must be handled accordingly, often requiring the extraction of the fuel with a barometer and its return to the supplier (with the corresponding claim).

Given all this, it is advisable to have a tank for the "receipt" of fuel and take a sample at the time of receiving the fuel (in agreement with the supplier and keep it sealed until the fuel is used without problems, and in case there are problems, the sample will show whether the problem was before or after the supply).

Fuel Receipt:

Fuel receipt control is very important. It can be **controlled volumetrically** (since the price is given per volume at a specific temperature), but because fuel volume varies with temperature, this task becomes somewhat complicated in each case because temperature adjustments must be made (using tables for each fuel).

This volumetric measurement is taken on the tanks, both for transport and for receipt, using previously calibrated rulers.

At the end of this manual, there is a mathematical method for calculating cylindrical tanks, but tanks can be oval or deformed during installation.

Therefore, it is advisable to **calibrate the rulers using water**, which is carefully controlled as it is introduced into the tank for calibration. This is the safest method for horizontal tanks.

A simple, relatively accurate way to control this is to weigh the transport vehicle before and after unloading; the volume will be approximately the product of the weight in kg and the specific volume in L/kg (or the inverse of the density, a value that should be supplied by the fuel seller), which is usually very easy to do.

The fuel receipt includes not only the volume (for which you pay), but also the characteristics of each type of fuel.

Among these characteristics, depending on the fuel, it's important to check the viscosity. This allows you to see how well it adapts to the pumping and atomization system, as it measures the effort required to propel it through the pipes.

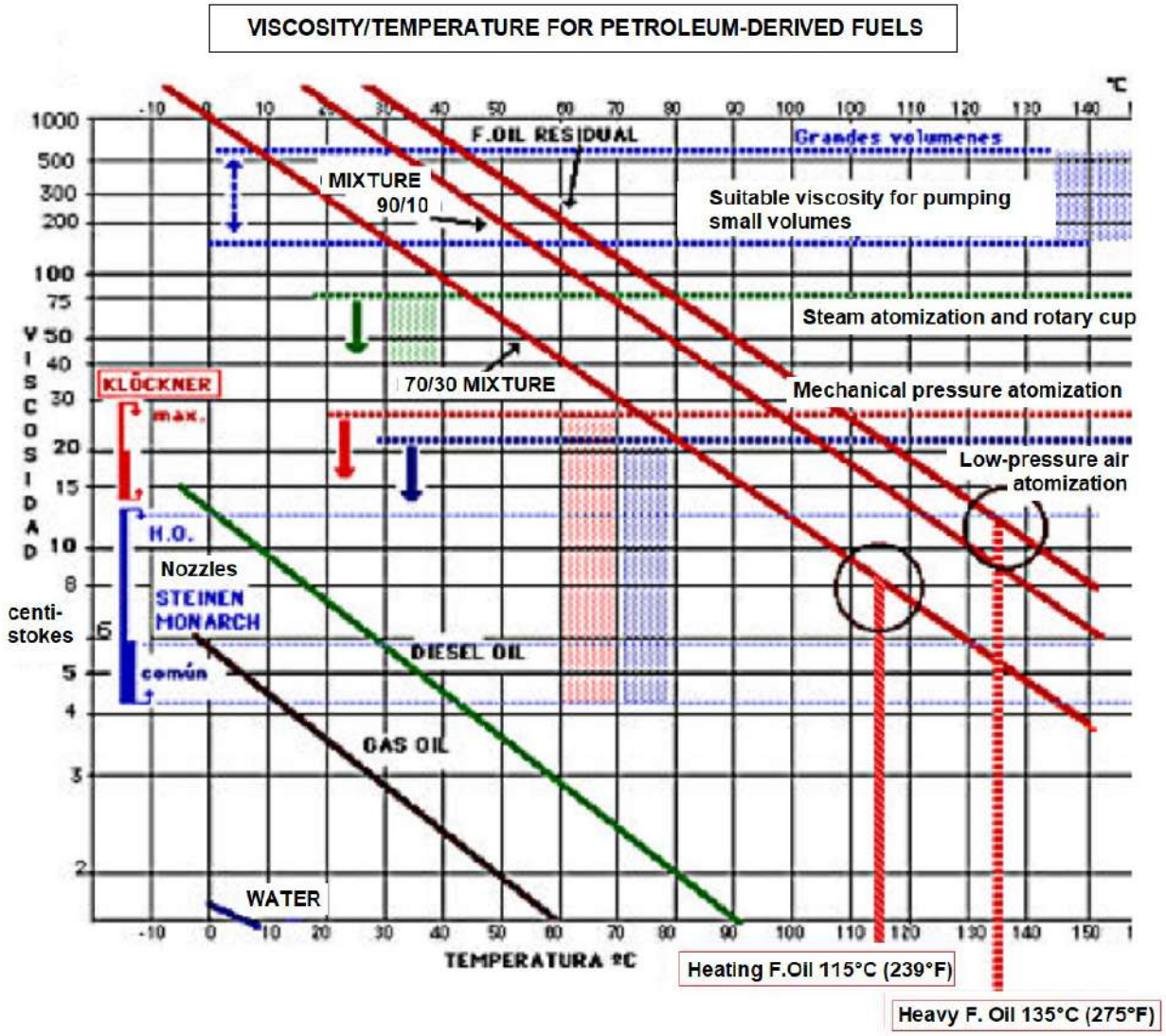
However, this value is related to the temperature at which viscosity is measured, which generally decreases as the temperature rises (i.e., it is easier to pump).

The fire point is the temperature at which the first combustion occurs when a flame is brought near the surface of the fuel. Since the safety standards for the use of each fuel allow us to work safely (remember that a heavy fuel oil with a flash point should not have volatiles that could cause a combustion explosion or fire when heated for pumping or atomization, since it is possible that due to an error in supply a fuel with other characteristics is delivered; the introduction of additives or other fuels with a low flash point should not be allowed either, it is dangerous).

Other analyses can be requested, such as the Higher and Lower Heating Values, maximum sulfur content, etc.
A good practice upon receiving the fuel is to keep a sample (a tightly sealed 1-liter bottle), in agreement with the supplier, so that if any fuel-related problems arise, this sample can be analyzed and compared with the analysis performed on the fuel in use.

In the following graph, you will see the most **suitable viscosities for pumping different fuels** (expressed on the left side of the graph in centistokes or kinematic viscosity, an international way of expressing viscosity, which can also be expressed in other ways: Engler degrees (European), Saybolt Universal (U.S.A.), Saybolt Furol (U.S.A.), Rewood

(England), etc., which can be converted from one to another using tables), as well as the **best viscosity for atomization depending on the fuel and the type of burner** (the most common burners or mechanical nozzles are indicated on the left side of the graph).



The viscosity of water is shown in the lower left part and the viscosity for heavy oil is shown in the lower right part, which is around 135°C (275°F) for mechanical atomization (with nozzles suitable for this, especially in small burners the nozzles will be indicated as H.O. or Heavy Oil, which means "heavy oil or fuel").

Residual fuel oil is heavy fuel oil (or No. 6). A 70/30 mixture would be heating fuel oil. Diesel oil has a higher viscosity than gas oil and is also more difficult to burn.

Never accidentally preheat gas oil and diesel in a burner that burns residual fuel oil. This can cause a combustion explosion upon ignition due to the vaporization of the lighter fuel.

If it is necessary to mix heavy heating fuel oil with gas oil or diesel oil, mix thoroughly before pumping it to the burner (by mechanical agitation or with air).

The percentage of lighter fuel should not be too high; generally, it should not exceed 20%. Otherwise, there is a risk of combustion explosion (if lighter fuel is preheated instead of the mixture).

BURNER HYDRAULIC CIRCUIT (fuel circuit)

Let's look at a sketch of a fuel oil system with a mechanical atomization burner with return flow control (although there will be many hydraulic circuits, depending on the type of burner, they all have the basic elements in common: tanks, pumping, heating, and **fundamentally all the control and safety elements**:

As we said, the automatic burner owes its operation to an **electrical-electronic programmer**, which performs all the sequences and controls or **receives all the signals from the safety elements:**
It checks that the fuel cutoff valves (in large burners there may be two serial cut off valves) are closed and will only be opened, feeding the atomization, if all the necessary requirements are met, such as: before strat there is a **sufficient water level**,

1.- first perform a pre-air purge (expel any remaining fuel gases from the combustion chamber; this operation involves changing the air in the combustion chamber and pipes 4 times or for 90 seconds with the "damper" (air inlet) open to 60%).

- The programmer will **monitor whether there is air for combustion** or airflow (without air there will be no combustion, but we will flood the home with fuel until the flame sensor closes the safety valve),

- Meanwhile, it will also receive the authorization that there is an **adequate temperature in the fuel** (an "anti-smog" thermostat, to avoid a cold start).

2.- the air returns to **minimum air for start-up** (a microcontroller monitors the minimum air position to prevent a start with excess air that blows out the flame or with excess fuel, since the air "damper" and the fuel regulating valve, if the burner is modulating, will be linked),

3.- **A pilot light is lit** (there may not be a pilot light). This light is usually bottled gas, and its ignition depends on an electrical transformer that raises the voltage of the normal supply line to more than 15,000 volts, causing a spark that ignites the gas.

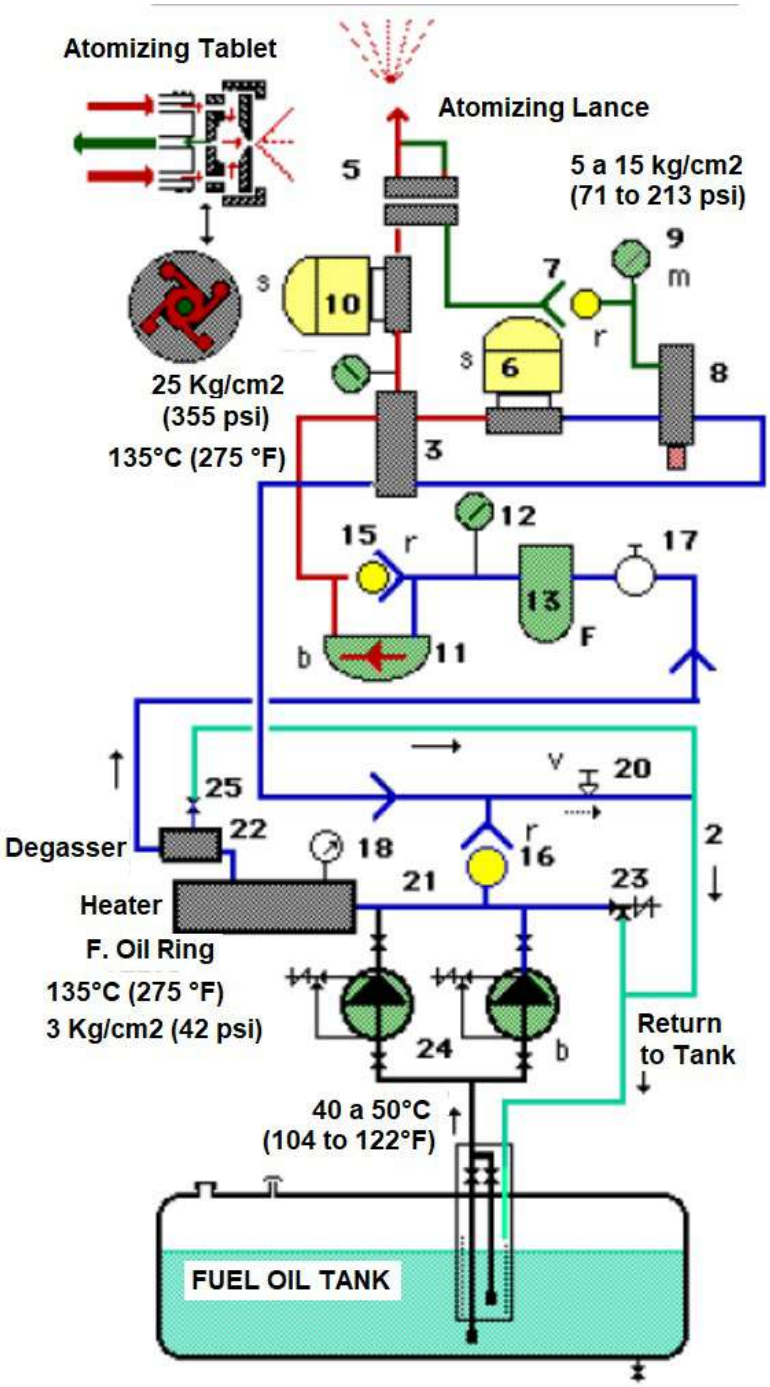
4.- **The pilot light will ignite for a few seconds (usually 10 seconds, provided it does not detect another flame or heat source that could ignite it in the home, to prevent a home explosion).**
Its ignition can be monitored by a flame sensor (photocell, which can be infrared to detect gas combustion, photodiode, or valve).

If the pilot light is not detected, the ignition process stops (this may trigger a complete cycle again or trigger a flame failure alarm, depending on the programmer). If the pilot light is not monitored or if there is no pilot light, the next step will be taken.

5.-The fuel supply valves for atomization will open in the idle condition, but **if the flame sensor does not detect the flame in 10 or 15 seconds, depending on the power and whether it has a pilot (15') or not (10'), the fuel cut-off valves will activate (closing) aborting the operation** (the action can be repeated automatically, doing a pre-purge again of shorter duration, depending on the type of burner and fuel).

6.- **Once the main flame is established**, if the burner is modulating, a few seconds will pass before the modulating pressure switch is enabled. This will cause the burner to regulate the power or fuel and air flow according to each steam production need (regulated by the steam pressure).

However, the **flame will always be monitored by the flame sensor,** which, depending on the burner type and power, will take between 15 seconds (small burners) and a maximum of 4 seconds (medium to large burners). **If it does not detect a flame, it will immediately shut off the fuel to atomization** (performing a new recycle, depending on the burner).



10 6 solenoids

8 return regulator

3 safety relief and cut-off valve

11 high-pressure pump

24 low-pressure pumps

7 15 16 check valve

20 manual return regulator

5 lance coupling

23 relief valve

22 degasser

9 16 25 pressure gauges

25 gas return valve

13 filter

17 valve

Generally, **if the burner fails** during one of its operations (after the recycle cycle, if applicable), it will remain off. An indicator light or alarm will usually illuminate, signaling the fault, until the operator presses a button ("reset") to return the burner to its normal operating condition and restart the burner.

It is advisable to check for any problems, which could include: a photocell clogged with soot (failing to detect the flame properly), dirty fuel filters, insufficient fuel, insufficient combustion air (due to a broken fan shaft), broken fuel hoses, cold fuel, water in the fuel, a malfunctioning fuel pump or

air entering the suction line, or a lack of fuel altogether.

There will generally need to be **electrical interlocks between the different operating elements, such as the shut-off valves** (which should generally close in less than 1 second, like solenoids) not being enabled by the programmer if the fuel pumps are off, if the fan is off, induced air draft if there is one, etc.

Similarly, the possibility of electrical faults in the circuits, such as short circuits, grounded wires, etc., must be considered, so that **under no circumstances should the burner shutdown be overridden if the boiler has a low water level**. **If the pressure exceeds the limit, the safety valves will open, but if it runs out of water, the boiler will malfunction: it will burn out or something else related to that, such as an explosion if the conditions are right.**

The sketch above (the atomizing lance drawing) shows a fuel oil system with mechanical atomization and fuel return recirculation regulation (in the atomizing state) to vary its atomization flow capacity without affecting the atomization quality.

The **Fuel Oil tank**, in the case of heavy F. Oil, must have a **heating system** to bring the temperature to at least 50ºC (122°F), to lower the viscosity to that of low pumping (generally a steam coil, surrounding the fuel inlets, with its thermostat and temperature control solenoid).

The thermostats have not been installed here (a fuel heating temperature regulating thermostat, a high temperature cutoff thermostat with reset if it is electric heating and a low temperature protection thermostat or "anti-smog" in case the F. Oil is too cold (turns off or does not allow the burner to ignite).

Note that there is a **"low" fuel pressure ring**, whose function is in heating and supplying the fuel, and a high pump circuit for atomization (which works with the fuel already hot, which makes its job difficult, since the fuel itself is the lubrication of the pump's gears and seals).

There are two solenoid valves: one normally open (No. 6), which allows fuel recirculation when the burner is off, to keep the circuit "hot" almost to the nozzle, and another **normally closed (No. 10)**, which enables fuel to flow to the nozzle for the burner to operate.

There is also another mechanically actuated **safety valve (No. 3),** which has the dual function of closing when the burner shuts off and regulating the maximum pressure of the high-pressure pump for atomization.

Valve No. 8 regulates the combustion capacity, returning fuel, controlled by a modulating motor (governed by a modulating pressure switch) and which also regulates the combustion air intake to maintain the air/fuel ratio.

Low-pressure pumps must have a permanent internal or **external relief valve**, since they are positive displacement pumps. If they do not relieve pressure when the valve is closed, they would build up so much pressure that they would "break" the pipes or any element that cannot withstand the pressure, or even the pump shaft, or in the best-case scenario, they would trip the motor's thermal overload relays.

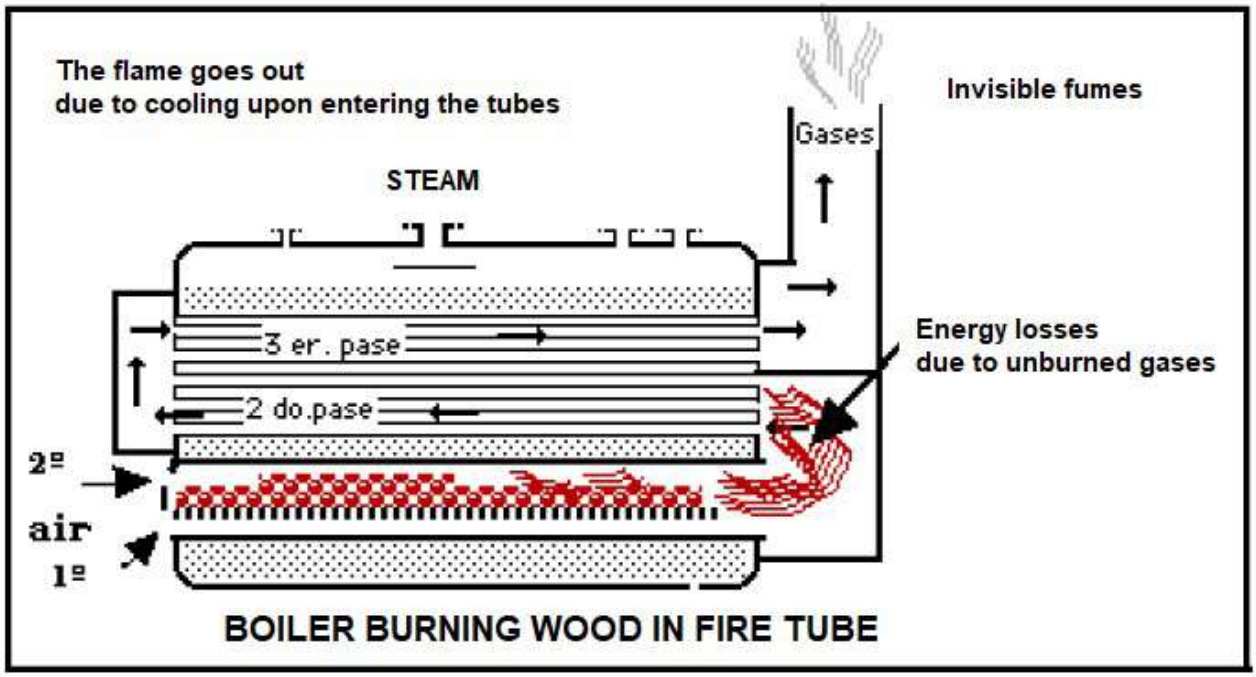
The fuel heater (F. Oil), generally if the boiler is relatively large, will be a **combined electric-steam heater or two separate heaters, one steam for normal operation and one electric for starting.**

The deaerator at the outlet of the heater allows the extraction of gases and water vapor evaporated by the high temperature (since the saturation temperature of water is higher than that corresponding to the low pressure).

If these gases interfere with the high-pressure pump, it causes alterations in the high pressure, resulting in poor atomization.

CHAPTER 5: Operation Part 3

LET'S SEE HOW WOOD-FIRED BOILERS ARE OPERATED



START-UP OF WOOD-FIRED BOILERS

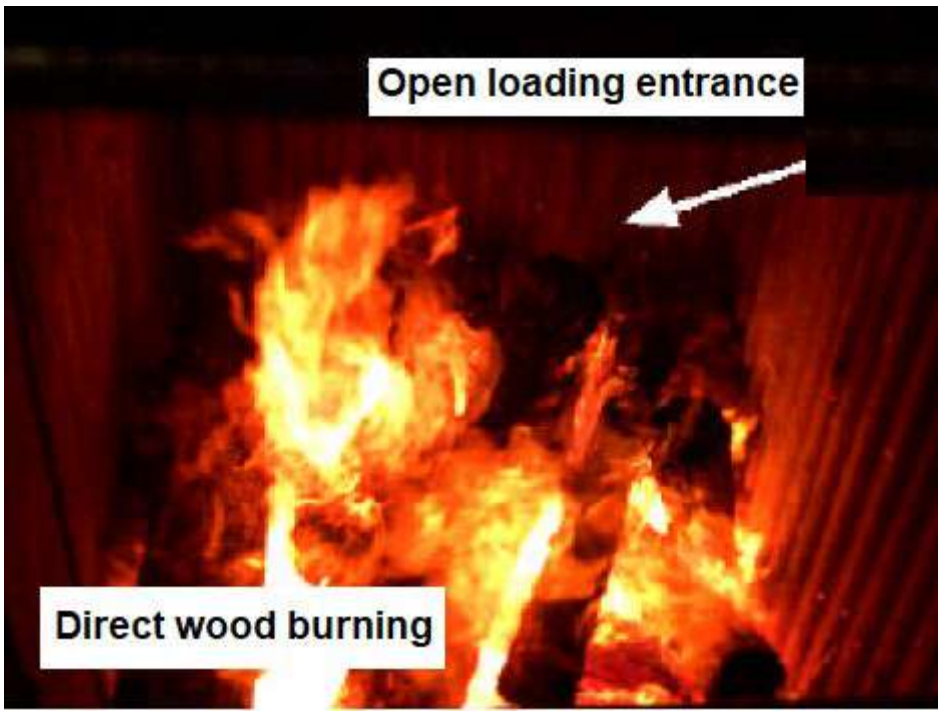
Wood is an excellent fuel. Its carbon and hydrogen content gives it a good calorific value, although it already contains a significant amount of oxygen, which we assume is already bonded to the hydrogen (therefore, wood combustion is similar in its gas emissions to coal combustion, producing a high CO2 content on a dry basis, almost over 20%). The most undesirable element in wood is water or moisture, but the sulfur content is practically zero.

We must clarify that the firewood we normally use in boilers is eucalyptus wood and not forest firewood, which, although it is a national heritage that should not be consumed, not only for this reason, but because in its combustion it produces an ash that melts like glass, which clogs the grates or grills, affecting the operation of the boiler; this does not happen with eucaliptus wood.

Although firewood produces a high CO2 content in its smoke, it has the advantage that this CO2 is consumed by the tree itself during its growth or wood formation. In other words, a balance is created between the CO2 produced and the CO2 consumed, which means that it does not accumulate in the atmosphere, as happens with fossil fuels (coal, oil, and other natural

liquids and gases extracted from petroleum).

We must divide into two cases: **1- direct burning boilers** and **2- gas generator burning.**



When starting up a boiler, the first step is to check all the components involved in its operation:

1- Verify that it is filled with suitable water (softened, chemically treated, etc.) to almost the normal level (1/4 of the visible level or the pump's automatic cutoff, as the level will rise as the water temperature increases).

To fill the boiler, close all the drain valves and open the atmospheric valve (air vent). It is assumed that the main steam valve (throat valve) is closed.

If the boiler is in a dry storage condition, first remove the drying agents from inside (quicklime, silica gel, etc.), install access panels, and perform a leak test (hydraulic).

If it is flooded with treated water for a wet storage condition, it is generally sufficient to lower the water level using the drain valves, opening the atmospheric valve to break the vacuum (to allow air to enter).

2- Check the level controls (open their purges and verify that the feed pump is activated, before opening their suction and discharge valves; listen and look for signs of low level). In some cases, it is necessary to perform a **hydraulic "leak test"** (test for water or steam leaks).

To do this, you can slowly build up the "working" pressure using the same wáter **feed pump**, venting the air through the **atmospheric valve** (the atmospheric valve serves both to vent air and gases and to prevent a "vacuum" from forming inside the boiler when cooling or emptying it).

After 10 minutes of pressure (with all valves closed), observe the exterior and interior of the boiler (firebox and smoke boxes) for **water leaks**, and ensure that the pressure on the gauge does not drop more than very slowly (this indicates a leak in the packing). Then, slowly lower the pressure (purge) and regulate the level (purge and atmospheric valve). Finally, proceed to start the boiler.

Remember that **combustion will be handled by the air that enters the home**, below the "grill" (primary air) and above the "grill" (secondary air) and that they will depend on the **opening of the registers** and the **depression of the home** ("vacuum" caused by the natural draft of the chimney or by an **induced draft fan**).

Since the wood load is normally stable (a certain height above the grate), **to increase combustion we must increase the air below the wood,** so that combustion occurs whose heat volatilizes some of the wood.

This "wood gas" combusts with the "excess air" that entered below the grate, **establishing a bright, high-temperature flame.**

What allows for rapid combustion of the gas is the air already heated in the **primary combustion zone** and the **air that enters above the grate, the secondary air**.

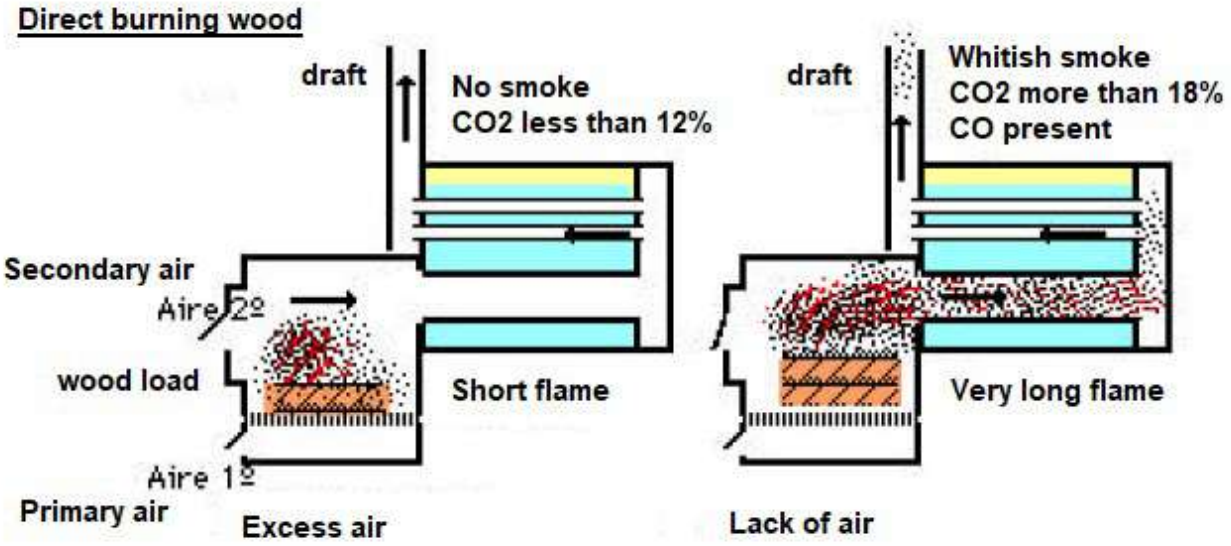
Many of these boilers **preheat the air that enters under the "grate"** by taking advantage of the heat from the flue gases (lowering their temperature to less than 160ºC 320°F), in order to **increase the efficiency of the boiler** (making better use of the heat) and improving combustion conditions (at a higher temperature, combustion is "faster" and wood with a high moisture content, more than 40% moisture, can be burned).

This preheating is possible because the grates are "cooled" (the grates that make up the grate are made of a special alloy cast iron). When mounted on tubes through which the boiler water circulates, this allows the metal of the grate to be "cooled" (preventing its temperature from becoming too high), while simultaneously preheating the air and the grates (whose temperature will be at least close to the temperature of the boiler water).

The air can then be "preheated" without the risk of "burning" the grates at temperatures exceeding 150°C (302°F). (This increases the combustion reaction rate, ensuring that combustion occurs before the air leaves the combustion chamber).

The fact that the primary air is preheated (with or without an air preheater) means that this air plays a fundamental role in complete combustion, with secondary air being used only at high vaporization rates.

The combustion of carbon and hydrogen occurs in different stages. Even the low moisture content of the wood is favorable to this combustion, as it interacts with the carbon at high temperatures and causes gasification in the combustion chamber, which promotes flame formation (a luminous flame is very effective for heat transfer by radiation).



Boiler Start-up:

It is important to properly purge the firebox with air (by opening the induced draft and dampers 1 and 2) and **never use liquid fuels that can gasify (be careful, if the grill is hot: diesel, oils, or even fuel oil can gasify).**

Always maintain negative pressure in the firebox and a small purge. Whenever working with the firebox open, you must maintain negative pressure: **never open the firebox with the damper closed and/or the induced draft turned off**.

The air entering through the loading port may cause the gases inside the firebox to ignite (since there has been no purging of the flue). **This can happen while adding dry or dampened combustible materials (such as cardboard, tow, husks, paper, kindling, etc.) if the fire is not yet hot.**

Use a cotton swab to light the base of these materials and gradually add more wood (thin logs, slabs, etc.) until you can add logs of sufficient size.

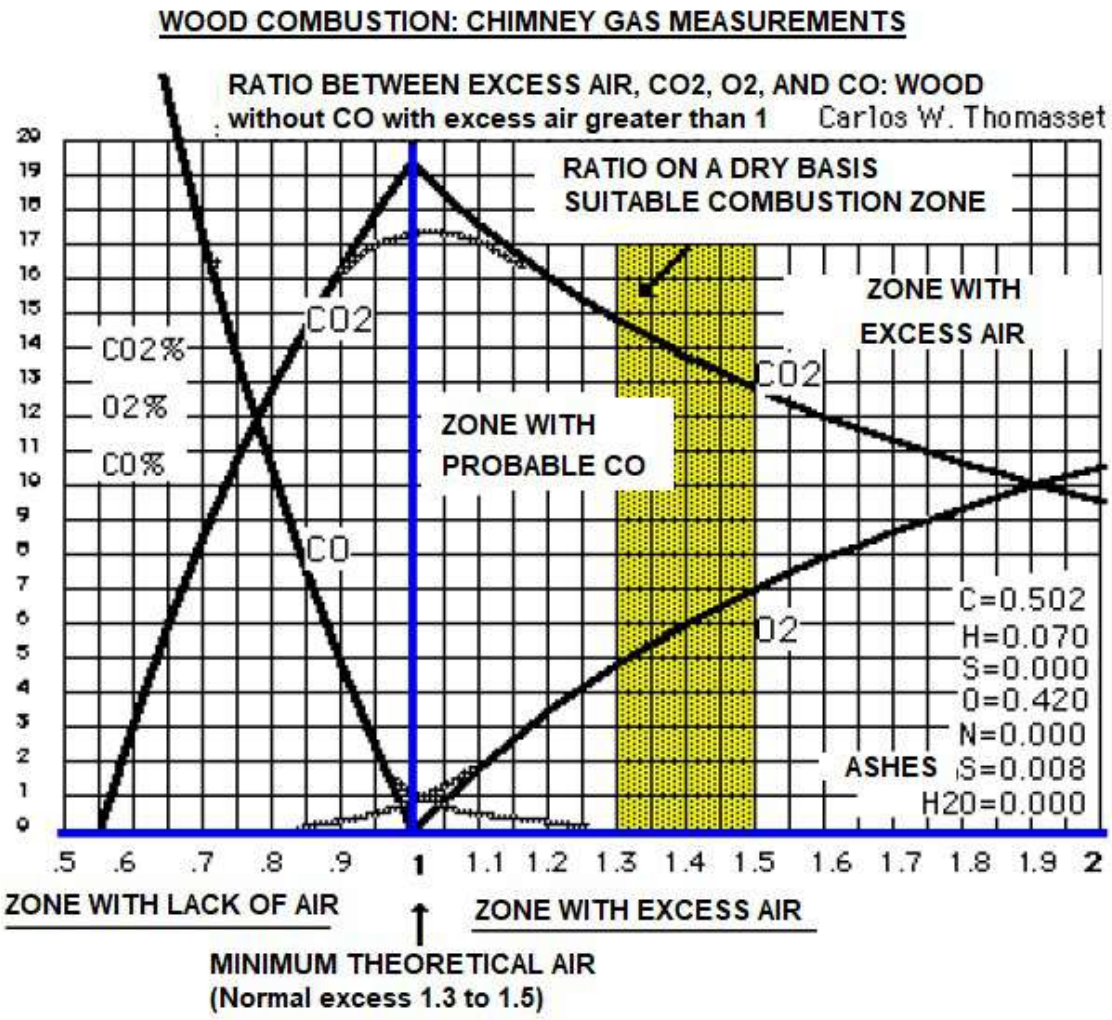
Do not build a large fire with a cold boiler; heat the entire boiler gently and evenly.

Initially, work the fire with "excess air" (by keeping the damper open and supplying air through dampers 1 and 2, as combustion will be inefficient in the cold firebox).

A cold boiler should be warmed up over several hours (2 to 8 hours, depending on the boiler), and if the boiler has been off since the previous day, a couple of hours will suffice (1 to 2 hours, depending on the type of boiler).

We reiterate: do not introduce liquid fuels by "pouring" them through the loading hatch, as this can cause a combustion explosion (when they vaporize and mix with the air inside the combustion chamber, they form an explosive mixture).

Never open the loading hatch with the draft closed (natural or induced) or the induced draft fan turned off (when there is insufficient natural draft).



Combustion regulation in direct burning:

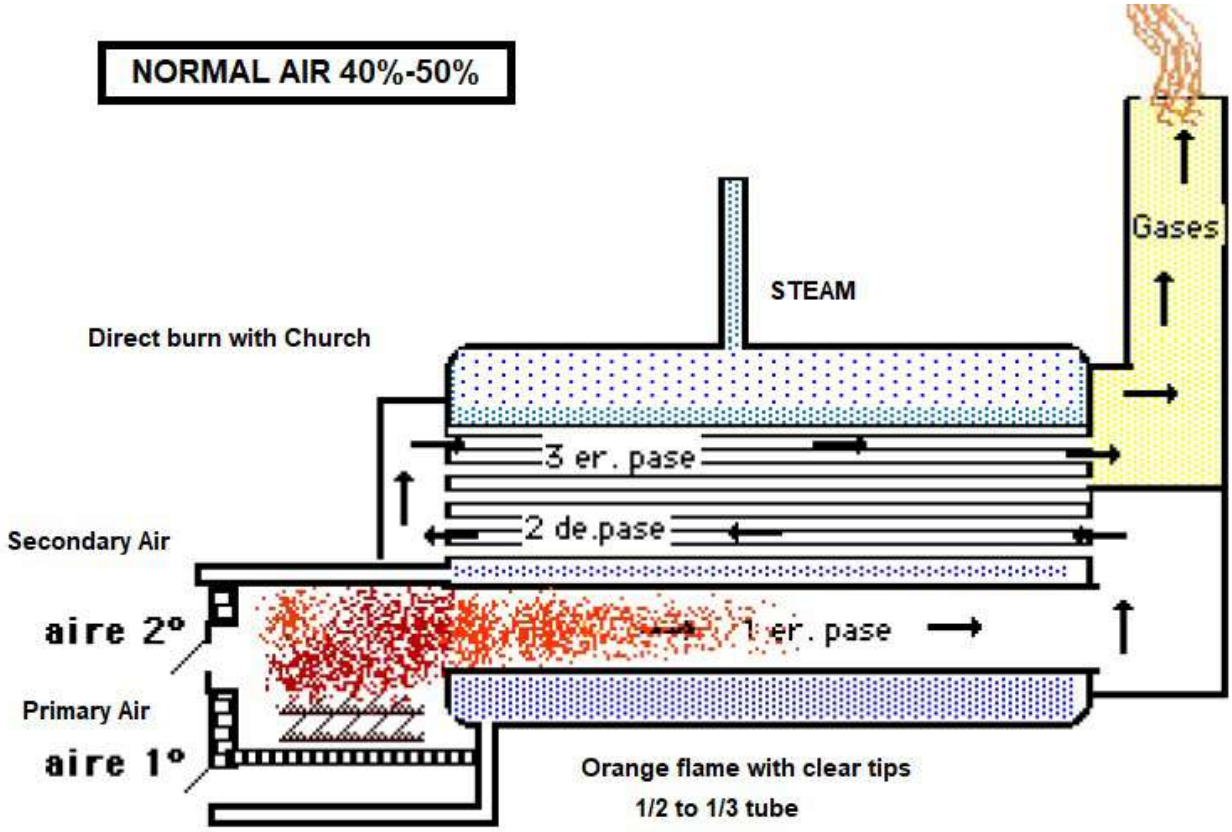
1.- Lack of air:

Since black smoke is not present (generally only whitish, like "vapors", or if the lack of air is very noticeable it can produce somewhat blackish smoke) the measurement of gases plays an important role, since in the absence of smoke there can be a CO2 of 16% to 18% with a significant presence of CO (for every 1% of CO the loss through unburned gases in the chimney can be more than 5%).

Sometimes it's preferable to keep CO2 between 14% and 16% to avoid the possibility of CO formation (since, in addition to energy loss, carbon monoxide carries tars that tend to foul the heat exchange surfaces). There may be a real or perceived lack of air.

Both are caused by the use of firewood with high moisture content (more than 35% moisture), an overloaded firebox (which prevents even airflow under the grate and causes "distillation"), overtaxing the boiler's capacity, poorly regulated airflow, grates clogged with ash (due to lack of cleaning), insufficient stirring or stoking of the firewood on the grate, and a dirty boiler with restricted air passages: clogged tubes, ash-covered pipes, etc.

The amount of combustion is regulated by the amount of air forced (or drawn in by the draft) under the grates ("grate"), for a given height of wood. With secondary air, we regulate the flame length (completing combustion at high speeds), and with induced (or natural) draft, we maintain a negative pressure in the firebox (-3 to -5 mm H_2O: millimeters of water column) to manage the resulting volume of combustion gases (and the primary and secondary air intake if there are no fans).



To gain a practical understanding of combustion, we must observe the fire in the central flue of the firebox or on the convective bank (water-tube boilers).

Combustion should not reach the bottom of the firebox or the convective bank; it should end before the flame cools.

When measuring flue gases, it is advisable to use an **Ostwald triangle** for

wood to verify that the three readings converge at a single point on the triangle (are consistent). See the Efficiency chapter.

2.- Good combustion:

In this case, practically nothing is visible in the chimney (a light vaporous veil or nothing at all). CO2 will be between 14% and 16%, O2 between 3.5% and 6%, and CO will be 0%.

Using the flame as a guide, it should enter the central flue of the firebox halfway (in the convective bank of water-tube stoves, it should "lick" the tubes).

Adjust the secondary air and/or the wood load to shorten or lengthen the flame.

To maintain these values, it is advisable to load the wood in short bursts, stir the wood between bursts, and use relatively dry wood (25% to 30% moisture). Do not overload the firebox with wood, keep the grates clean, and it is highly recommended that the firebox depression (induced draft) and primary air (forced air under the grate) be automatic.

The firebox depression should be between -3 and -5 mmWC, with a depression sensor controlling the draft, modulating a butterfly valve or damper, etc., and the forced air under the grate should be modulated by the steam pressure: as the pressure decreases, the air increases, and vice versa.

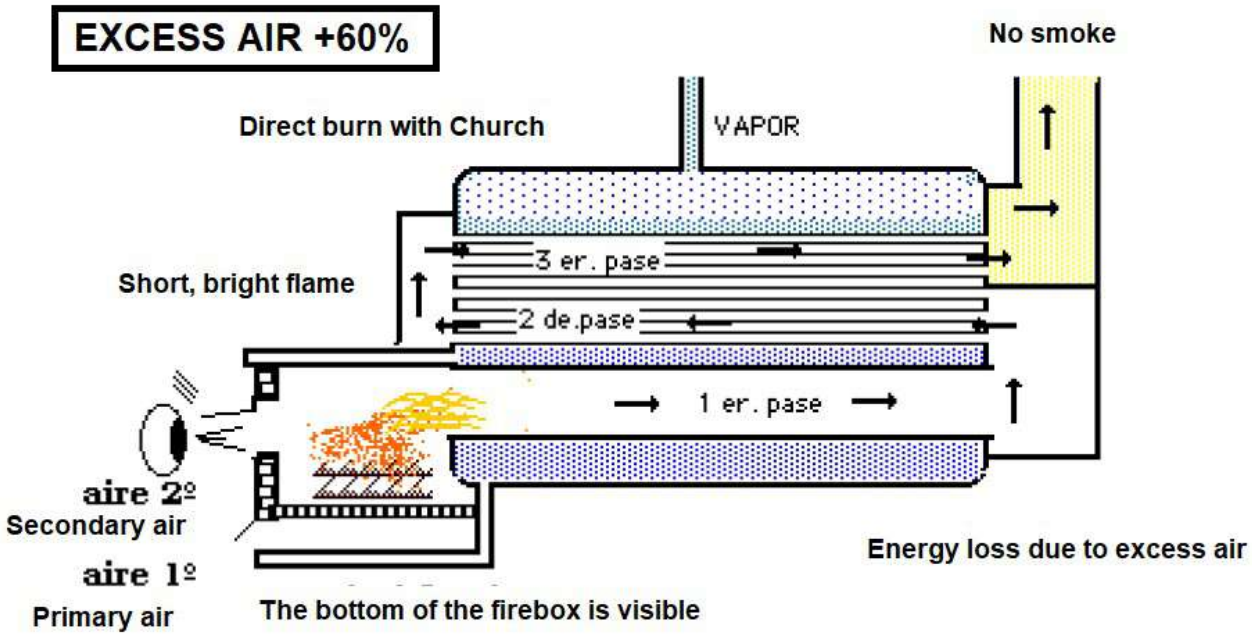
Automation allows for highly regulated operation, leaving only the management of the wood and secondary air (which can also be automated) to be handled manually.

However, if the pressure reaches a maximum, closing the air and gas valves, a pressure switch will shut off the induced draft and the fan under the grate.

Remember: Do not open the loading door or the observation hatches when the flues are off.

If the pressure rises above the working pressure due to thermal inertia, the first safety valve or service line valve will open.

Since direct wood burning results in high vaporization in the combustion chamber (the "chamber" is exposed to radiant heat and vaporizes 40% to 60%), the boiler responds quickly to changes in vaporization requirements.



3- Excess Air:

In this case, nothing is visible in the chimney (only hot gas). CO2 will be below 12%, O2 above 8%, and no CO (there may be some CO present in some cases: a cold flame).

The flame appears very short, the central flue of the firebox is empty of flame, and there is no flame at all.

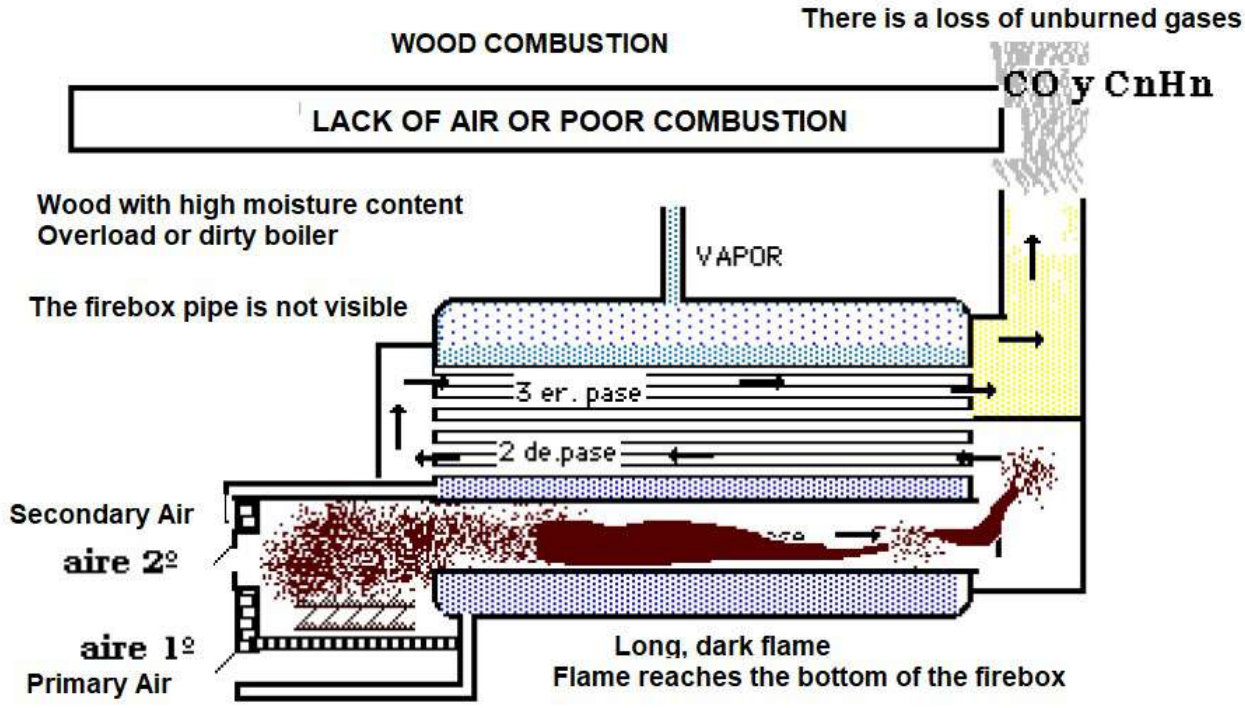
This is caused by: a very low wood load, a poorly covered grate, excessive air intake above the grate, excessive draft in the firebox (more than 5 mm H_2O), insufficient stoking of the fires, improper adjustment of the air controls, unauthorized air intakes, etc.

4- Poor Combustion:

Poor combustion can occur even when the amount of air and wood is correct.

The flame may be long at certain times and short at others, and this is generally due to excessively damp wood (more than 40% moisture content; more excess air is needed as the moisture increases), or excessively spaced

loads (this forces overloading the grate, initially causing insufficient air and later excess air), or that wood that has not been stirred or stoked, poorly regulated or fluctuating air, a dirty boiler, etc.



SHUTTING DOWN THE BOILER

To shut down a direct-combustion boiler, simply close all air vents (especially the intakes to the combustion chamber and the flue: without oxygen, there will be no combustion). Sometimes it is advisable to create a slight negative pressure in the combustion chamber to prevent gases from escaping into the boiler room.

If the boiler is shut down permanently or until the following day: reduce the wood load a few hours beforehand so that at the end of the day there is almost no wood left in the combustion chamber, allowing the remaining wood to burn gently (don't worry if it is necessary to allow a steam vent to limit the pressure).

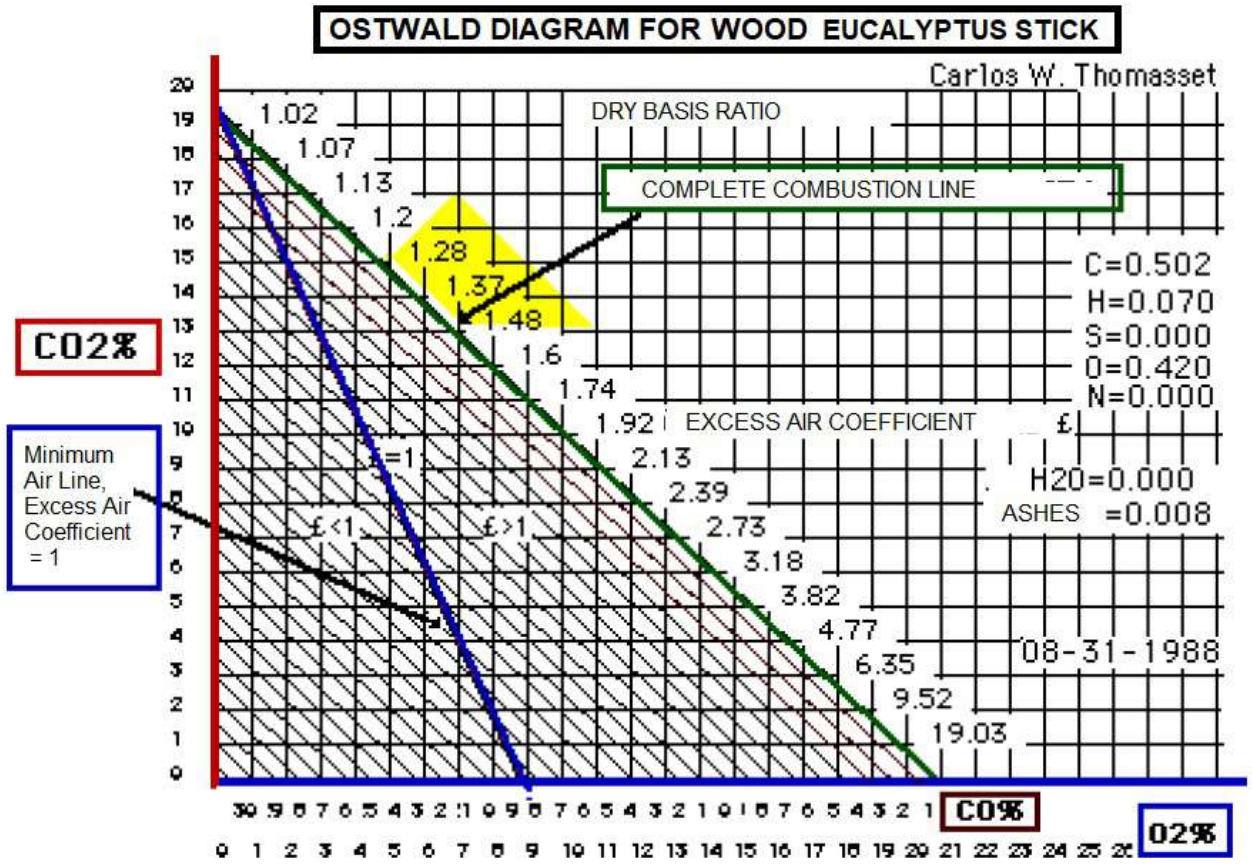
This is generally not necessary, since if the pressure rises above the operating pressure, the safety valves or the line relief valve will take care of lowering it. What should not be done is to cut off the water supply under any circumstances and not to try to depressurize the boiler by indiscriminately releasing steam into the atmosphere.

In boilers using cellulosic fuels (wood, husks, etc.), it is important to have an auxiliary water supply system one that does not depend on electricity, such as a steam injector or a steam-powered pump.

This auxiliary system should be used during power outages (or failures in the normal supply), but the main steam valve must be closed (even more so if there is a lack of supply) and the air vents closed to keep steam production at zero (remember that the plant will not operate normally without electricity, although steaming can continue using natural draft and this auxiliary supply).

Steam injectors must be fed with cold, preferably softened water (since using hot water from the same feed tank may prevent the injector from functioning because its operation relies on steam condensation: the transformation of thermal energy into dynamic energy, and the use of hard water can cause scale buildup that blocks the small orifices and conduits that make it up).

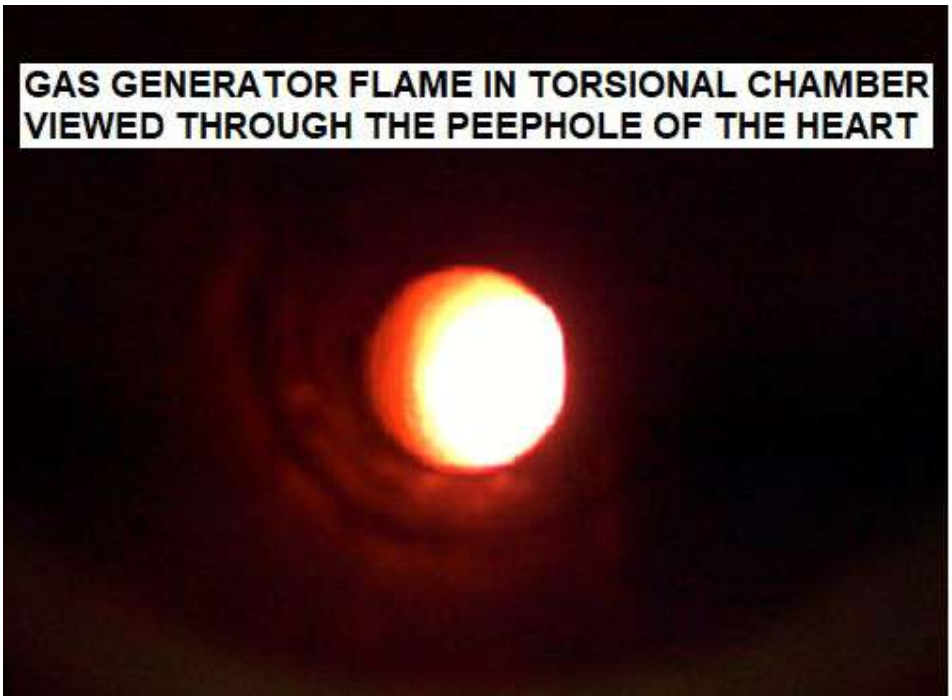
Reciprocating steam pumps ("donkeys") tend to seize up due to prolonged inactivity and should be tested regularly (daily or weekly) using appropriate lubricants (since contact with water and steam tends to affect lubricants not specifically designed for this function).



Boilers equipped with **air heaters** will greatly benefit in combustion and heat recovery (efficiency). However, **these heat recovery heaters must be cleaned periodically (once or more per month) on the flue gas side** (using hot water to remove accumulated ash is highly beneficial).
In some cases, a hot water washing system can be installed while the boiler is running, thus avoiding a complete shutdown. The same feedwater can be used.

CHAPTER 5: Operation Part 4

WOOD GASIFIER BOILERS



The gas generator must be lit with greater care than direct combustion. All the precautions noted above must be taken, in addition to the fact that we have primary combustion and then the gas produced must be burned in a secondary combustion, separate from the first, in the boiler's combustion chamber.

First, the gas generator is lit by operating the draft. Initially, combustion inside the gas generator will be complete with very little gas formation (there is an excess of air inside the gas generator due to the relatively rapid initial combustion).

Next, you will see that the temperature of the gases entering the boiler's combustion chamber begins to rise (indicating that the gasification volume is becoming significant). Subsequently, as the primary air (and the wood load) increases, the gas composition (CO and other gases) also increases.

At this point, a pilot light should be lit in the boiler's combustion chamber (generally using bottled gas or an auxiliary oil burner). By slowly introducing secondary air, a stable secondary flame is established between the gas produced by the gas generator and the supplied secondary air (generally

slightly heated if the boiler is warm, or cooled if it is cold). **Initially, the flame will be very unstable: little gas and cool air, with a tendency to produce pulsations.**

In some gas generators, although there is secondary combustion, because the connection between the boiler and the gas generator is of large section and short passage, the secondary combustion is actually an extension of the primary combustion, and in these cases the presence of pilot flames is not necessary.

The secondary flame can be checked through the sight glasses. Initially, a lot of "dirty" gases are noticeable in the chimney, but these will disappear (as the temperature of the gases entering the secondary combustion chamber increases, the flame stabilizes).

Secondary air regulation should be done using instruments or by observing a faint, pale bluish flame, ensuring it doesn't reach the bottom of the combustion chamber.

Upon entering the flue pipes, the flame is extinguished, quickly fouling them, raising the chimney temperature, and restricting gas flow within a few days.

The amount of secondary air will be related to the amount of primary air (according to the boiler's vaporization requirements).

The amount of wood loaded into the gasifier must be regulated by its height and the temperature of the gases as they exit the gasifier (since this reflects the height of the "bed" of wood chips or short logs above the "grate").

The temperature will decrease with an overload (very rich gas), or rise momentarily when the wood "bed" is lowered to a certain value.

The temperature will also decrease due to insufficient fuel for gasification.

Perfect gasification would produce approximately 1/3 of the heat available inside the gasifier.

The ash bed should not be allowed to sag, as this generates high temperatures (due to the high air velocity locally). **The ashes should not be completely removed, as this can damage the grates** (the rotating support).

The secondary flame must be constantly monitored, and if it needs to be extinguished, it must be reignited by piloting, slowly restoring the secondary air supply; otherwise, explosions or an unstable flame will occur in the home.

In some cases, a pilot flame is not necessary (reignition can be done directly from the gas generator).

Combustion is regulated by both **primary and secondary air, and the amount of wood must** be taken into account, as any of the three elements can affect optimal performance.

The greater the combustion requirement, the more gases are needed—increasing the primary air—to burn in the firebox with more secondary air.

TEMPERATURE, FLAMMABILITY LIMITS, AND FLAME SPEED OF GASES:

IGNITION TEMPERATURE IN AIR:

Hydrogen ... 580-590°C (1076-1094°F)
Methane ... 650-750°C (1202-1382°F)
Ethane ... 520-630°C (968-1166°F)
Carbon Monoxide ... 644-658°C (1191-1216°F)
Gas Oil ... 336°C (637°F)
Ordinary Coal ... 400-425°C (752-797°F)

FLAMMABILITY LIMITS IN AIR:

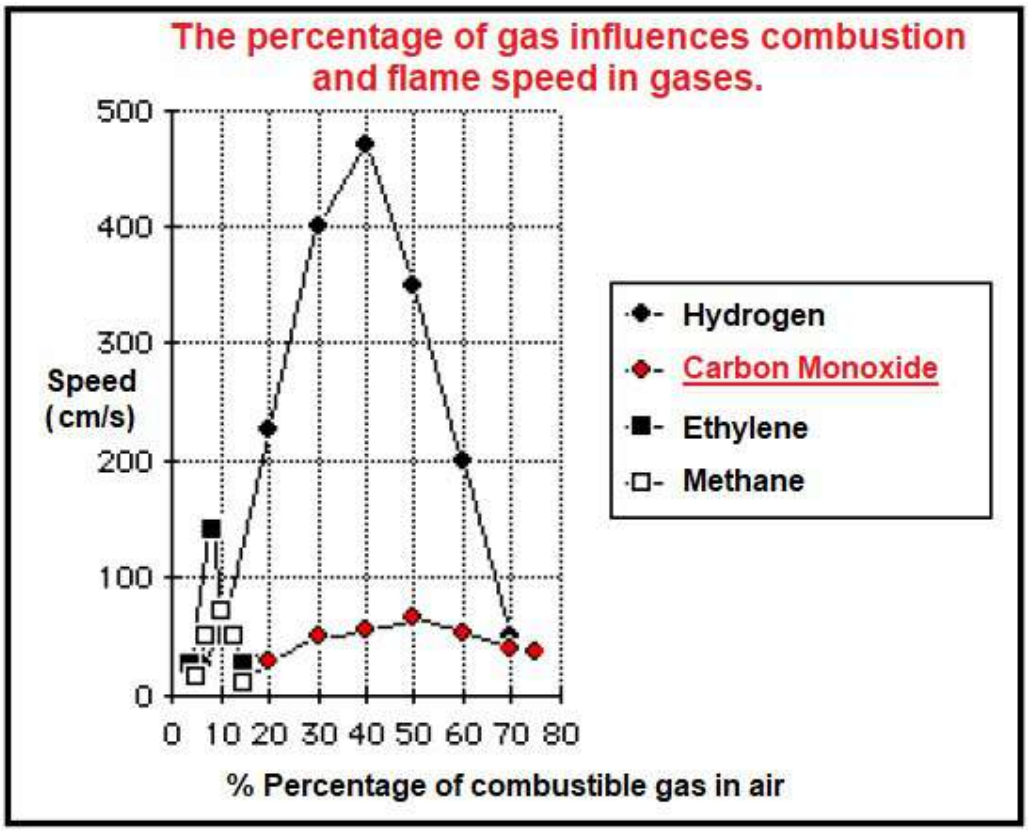
Lower Limit and Upper Limit %

Coal Gas ... 5.3% - 31%
Benzene ... 1.4% - 7.5%
Help Furnace Gas ... 35% - 74%
Carbon Monoxide ... 12.5% - 74%
Hydrogen ... 4% - 75%
Methane ... 5% - 15%

Since the wood in the gasifier is transformed into a gas at a variable temperature between 400°C and 700°C (depending on the wood load and the amount of primary air circulating among the wood, with little heat transfer within the gasifier itself), **we must consider that burning a gas is not as easy as it initially seems.**

For ignition to occur, minimum and maximum conditions must be met (and each gas has a combustion rate also related to these parameters).

In gasifier operation, factors such as the **height of the wood, its quality (including moisture, rot, bark, etc.), and the ratio of primary to secondary air in the combustion chamber play a fundamental role**.

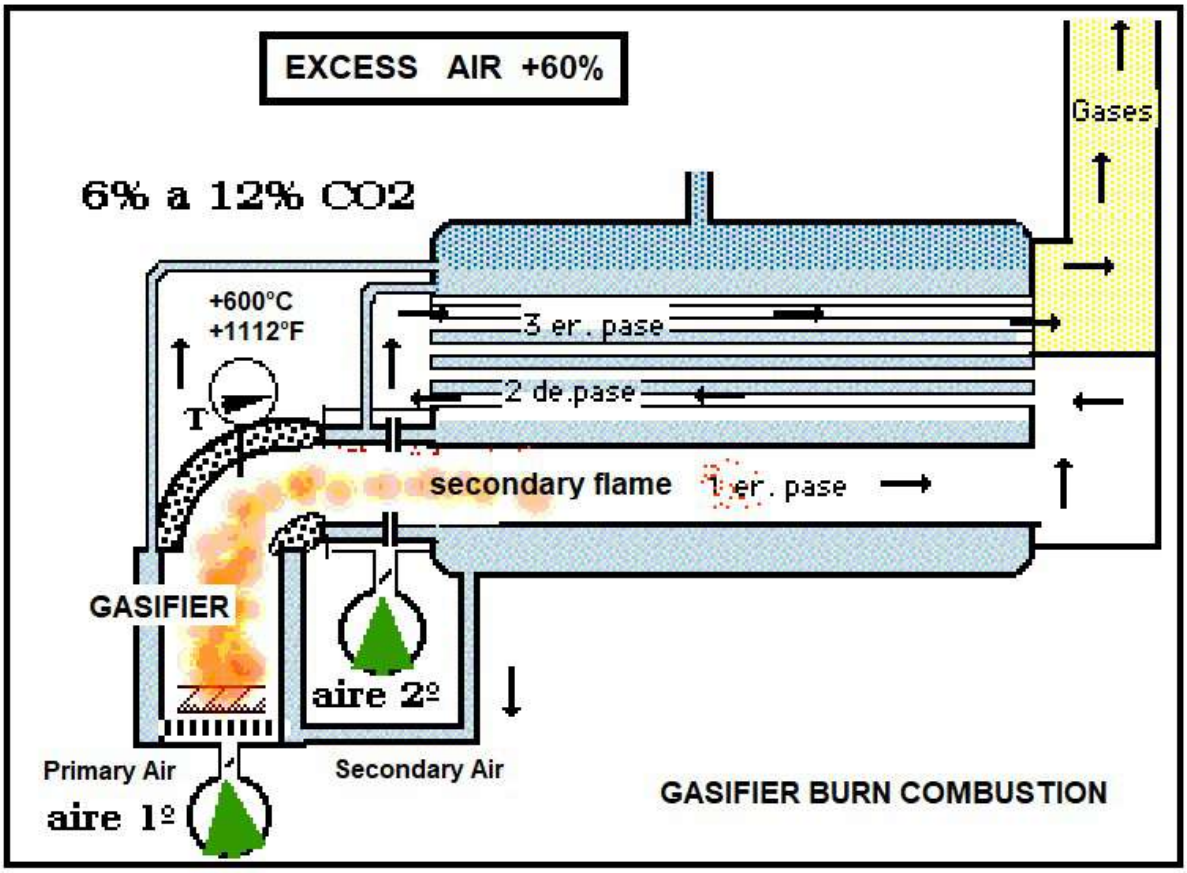


THE COMBUSTION RATE OF CO (carbón monoxide) IS LOW AT ANY CONCENTRATION

As we can see in the graph above, the combustion rates of the different gases vary with their concentration, with the lowest rate corresponding to CO (carbon monoxide). As it cools and its percentage in the gas mixture decreases, its combustion tends to slow down.

It exits through the chimney as a polluting loss if combustion is not achieved inside the combustion chamber (hence the importance I place on having an O2 and "unburned gases" meter in the chimney to ensure, as technically as possible, that combustion is complete).

Regulation of combustion by wood gas generator:

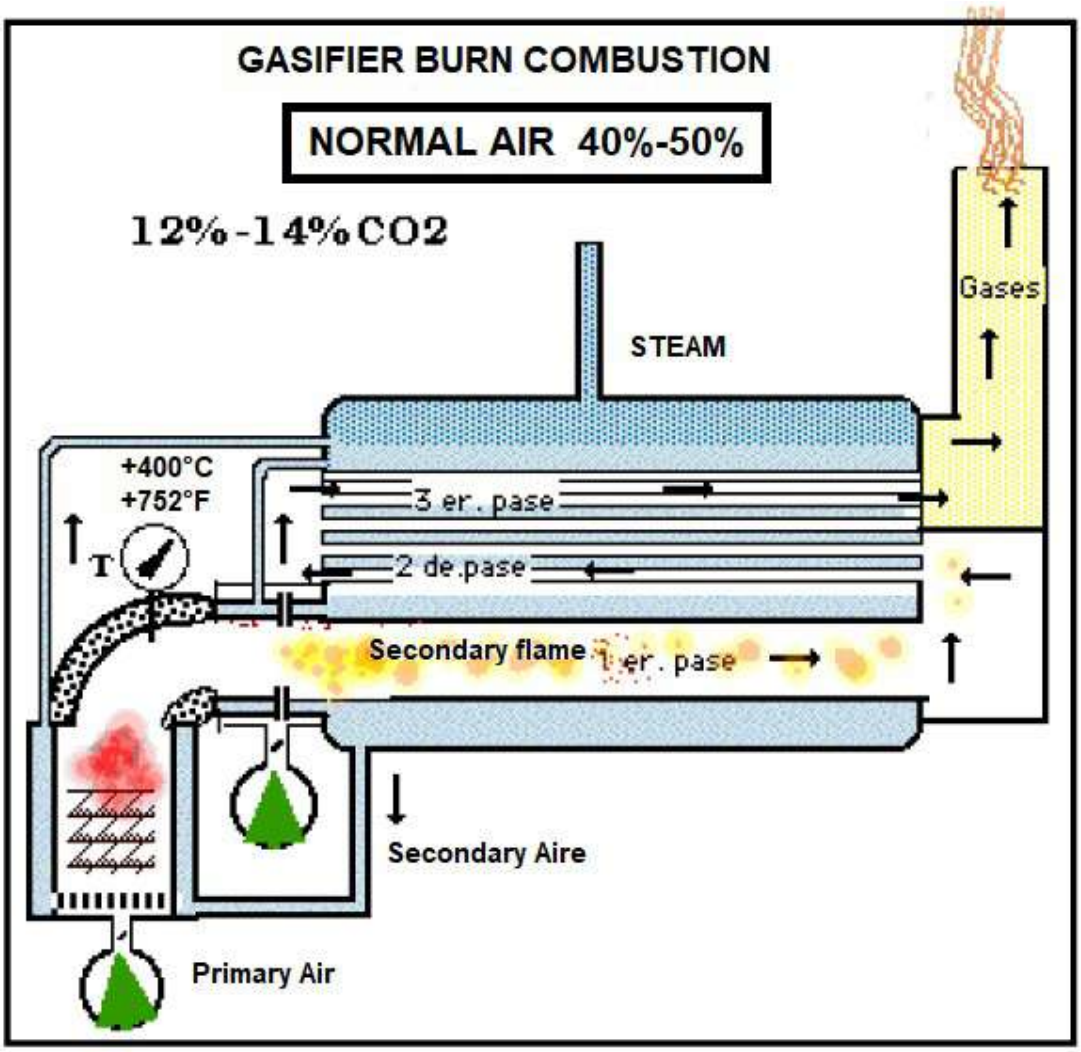


1-Excess air:

The secondary flame is very short, there is a luminous flame inside the gasifier, CO2 is less than 12%, and O2 is more than 8%.

There is no smoke in the chimney, and the temperature of the combustible gases is high (if there is sufficient wood in the gasifier).

When using instruments to measure flue gases, it is advisable to use an Ostwald triangle for wood to verify that the readings close at a "point": this confirms that the measurement is correct.



2-Good Combustion:
In this case, there is no smoke, the secondary flame reaches almost the end of the boiler's combustion chamber (although the very end of the flame is nearly impossible to observe), the gasifier charge is correct (height), the flue gas temperature is at an intermediate value, CO2 is above 14%, O2 is below 6%, **and there should be no unburned gases present (CO% equal to zero).**

Monitoring the flame in practice is difficult due to the lack of light during secondary combustion, so considerable operational experience is required to achieve these values.

It is affected by the general conditions we have given for firewood, but the moisture content of the firewood is less tolerable (it is advisable not to work with firewood with more than 30% moisture, and to use clean eucalyptus firewood, preferably without bark).

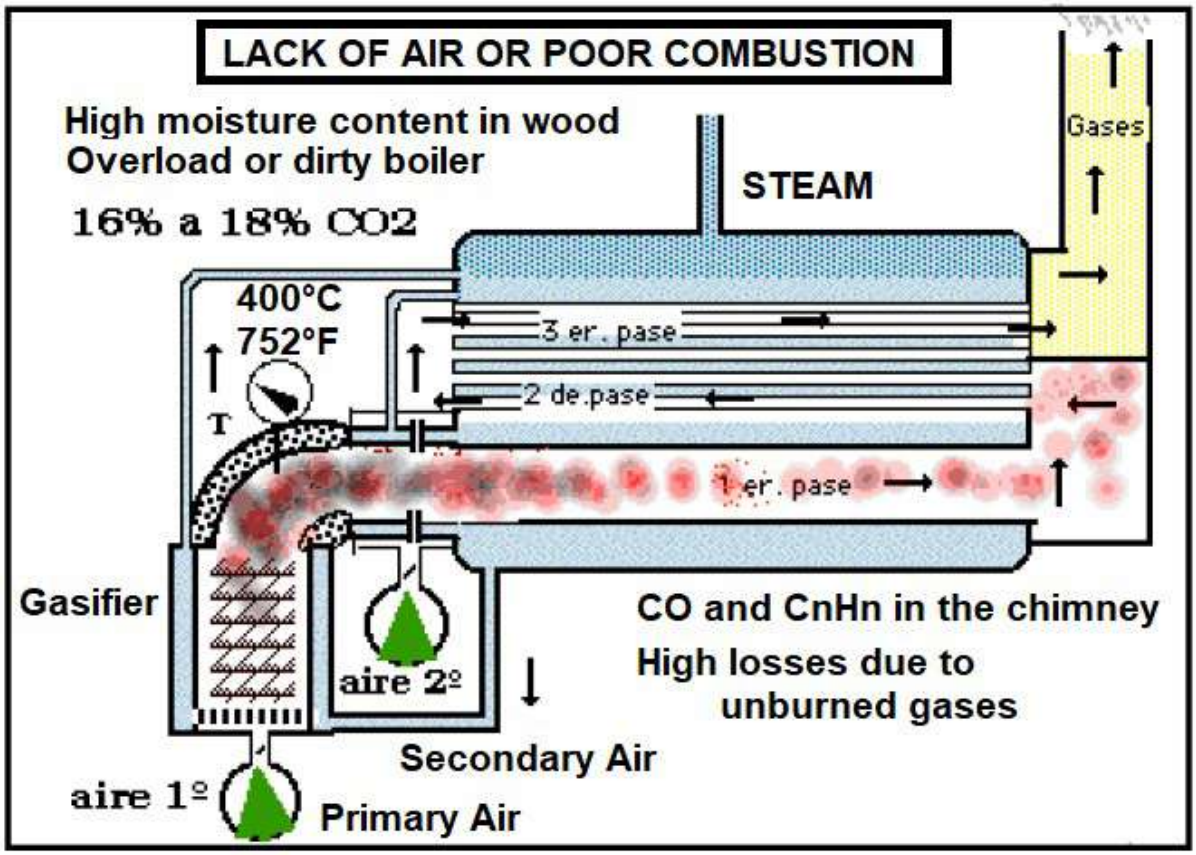
3- Lack of air:

In this case, some **whitish smoke is noticeable** (sometimes blackish if the lack of air is severe), CO2 is above 16%, O2 is less than 3.5%, and there is a **presence of unburned gases** (CO, accompanied by volatiles and tars that tend to dirty the boiler and corrode the metal chimney: cold areas).

The secondary flame appears dirty and very long (touching the rear sight glass).

The most common cause of this situation is the lack of air regulation and the wood load: overloading, wood moisture, wood quality (dirty wood, excessive bark, etc.), and a dirty boiler.

This situation causes the boiler to become dirty within a few days and lose vaporization and combustion capacity (due to insufficient gas transfer and passage; this is noticeable by a sharp rise in the chimney temperature, which lowers the boiler's efficiency).



4-Poor Combustion:

In this case, despite the total amount of air being correct, due to adjustments, complete combustion is not achieved, leaving unburned gases that are detected in the chimney (CO).

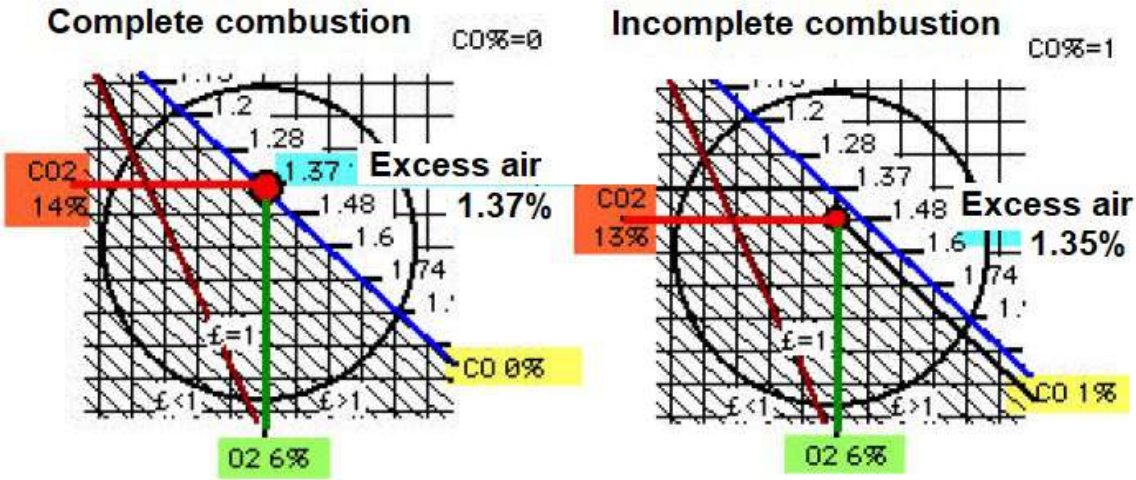
This leads to rapid fouling of the boiler (with an increase in the temperature of the exhaust gases and a decrease in the boiler's vaporization capacity).

One of the main causes of this condition is the moisture content of the wood (over 30%), which results in very cold secondary combustion and a longer combustion time in the firebox (reaching the end of the firebox without complete combustion).

Another cause is overloading the boiler, and since vaporization depends primarily on the secondary flame, heat transfer in the gasifier is minimal.

When the response is reduced for this reason, the boiler tends to overload to recover pressure. Under these conditions, the secondary combustion chamber is not large enough to allow sufficient time for combustion to complete, resulting in excess oxygen and unburned gases.

This characteristic requires the boiler operator to closely monitor steam consumption needs and anticipate these situations.



The graphs above (parts of an Ostwald triangle for wood) indicate the condition of complete combustion (CO=0%) and the condition where combustion is incomplete (CO%=1%), although with respect to O2 (oxygen).

In wood and gas boilers (such as natural gas), this results in very significant losses due to unburned gases (for every 1% of these gases measured in the chimney, more than 4% of the fuel can be lost through the chimney).

BOILER SHUT DOWN

To shut down the boiler, follow the instructions above for direct-fired boilers (C5 Part 3), ensuring that under no circumstances is any wood left unburned without attending to the boiler's water supply.

If it is necessary to restart the boiler, take care to purge the gases and create fresh gases before lighting the pilot light and supplying secondary air. (Follow the manufacturer's instructions.)

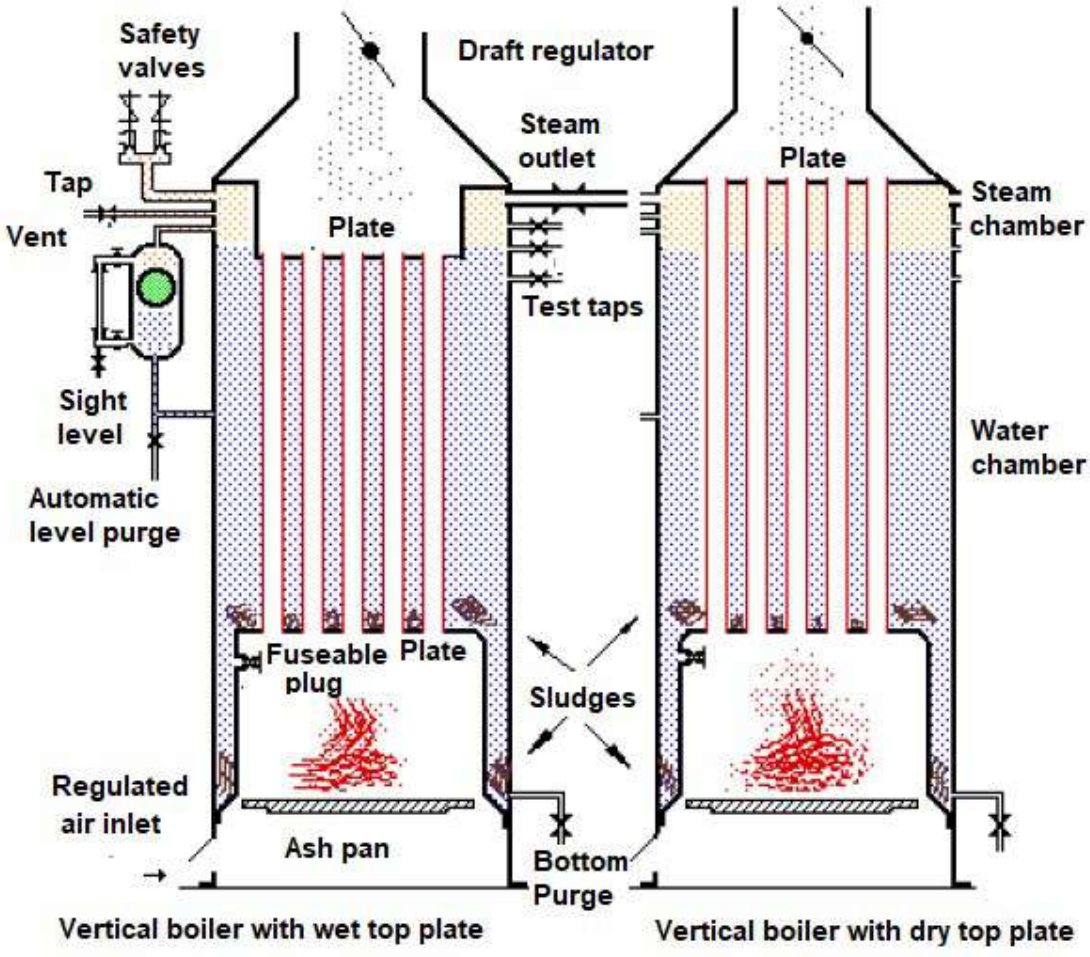
When shutting down, it is advisable to let the sludge "settle" for a few minutes (the steam valve will be closed) and **purge the bottom** (especially the gasifier, which tends to accumulate sludge because its circulation is not established in a liquid phase: siphon type) and the level controls (as with all boilers).

CHAPTER 5: Operation Part 5

VERTICAL FIRE WOOD BOILERS

If we consider vertical boilers, in this case they will generally be single-pass (a very short firebox pass and a tube pass, although in the past they were practically just a vertical cylindrical firebox with some large-diameter tubes that passed through it at an angle to allow the sludge to fall through, since it received heat from the firebox flame and could burn due to lack of cooling when clogged with sludge), as the firebox and the tubes are oriented in the same direction (although there are vertical boilers with more than one pass, they are not very common).

Let's look at a diagram for wood combustion (single-pass) in the boiler's firebox and evaluate its overall performance.



Vertical wood-fired boilers, which generally have low steam output (typically around 1,000 kg/hour), have both advantages and disadvantages.

Their primary advantage is usually the lower initial cost and ease of installation (generally requiring only a flat floor to support their weight and a chimney outlet in the roof).
Their primary disadvantage is their low efficiency or heat utilization.

Because they are single-pass (limited in the gas flow path), and because they are vertical single-pass systems, the chimney draft is very pronounced (although it can be easily regulated). **The "residence time" of the gases in the boiler is very short, resulting in low heat transfer and a high flue gas temperature at the boiler outlet.**

In two boilers with different flue gas temperatures, under the same combustion and fuel conditions, the boiler with the lower flue gas temperature has better heat utilization—higher efficiency—because the heat lost through the chimney is directly proportional to the flue gas temperature.

In the case of wood, single-pass vertical boilers generally produce less than 4 kg of steam per kg of dry wood (with 25% HB, and close to 3 kg/kg of wood in most cases, due to the loss we will explain below).

However, there is a loss that is not taken into account: the tubes are positioned so high above the combustion chamber that they draw in the flame (the flame consists of the combustible gases produced by the decomposition of the wood by heat, organic gases at different stages of transformation, including CO).

As we have said, the flame, upon entering the inside of the tubes, is extinguished, resulting in a significant energy loss of unburned gases (which can be measured in the chimney, but are not visible because, since wood gases do not produce smoke like fuel oil, the same occurs with natural gas and bottled gas).

This energy loss due to "unburned gases" can be very significant at certain times (when the boiler is operating at high loads, when there is a lot of wood in the firebox, when the wood has a high moisture content, when operating with insufficient excess air, etc.).

We mentioned that for every 1% of carbon monoxide (CO) in the chimney, between 5% and 7% of the wood is lost, but the boiler also "shrinks."

This is because the flame loses temperature in the firebox, thus transmitting less heat; the wood occupies a large part of the firebox, which then stops absorbing heat as it blocks and fouls the heat transfer surfaces; the boiler gets dirty quickly, which causes the chimney temperature to rise and further heat loss, etc.

The other problem to consider is that if the vertical boiler is a "dry" plate type (the top plate is in the steam chamber, with some of the tubes not cooled by the boiler water**), there is a high probability of tube loosening and cracking, as well as plate cracking between the tube holes.** This problem usually occurs during startup.

Since there is no steam in the steam chamber to cool the tubes and plates, when the boiler is cold and started up, the strong draft will cause a significant increase in combustion if care isn't taken to ensure slow combustion (gentle combustion, allowing time for the boiler to preheat at low combustion).

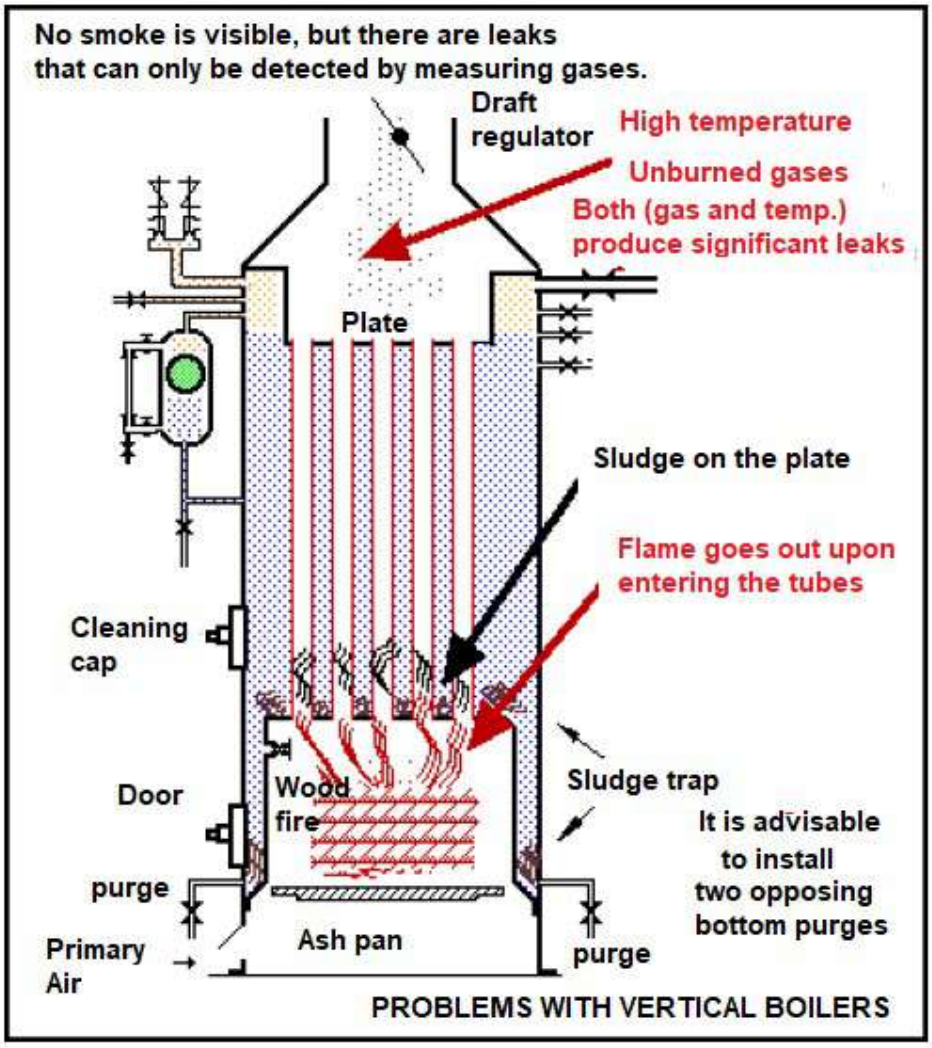
The flue gas temperature becomes very high, causing the tube mandrels (and welds) to overheat on the plates. This leads to "thermal fatigue" or overheating, which can cause the metal to "burn" or "soften," resulting in loosening or cracking of the tubes.

It's important to remember that as the boiler heats up, temperature differences cause expansion and contraction, creating significant stress between the plates, tubes, and shell. This can range from a simple stress crack to cyclic stress fatigue that ultimately leads to a crack.

Another disadvantage is that the water treatment must be designed to prevent internal sludge buildup, as this sludge partially falls onto the lower plate, which is directly exposed to the heat of the flame.

This can cause cooling problems (this sludge is very difficult to remove because the plate is horizontal and has vertical tubes, making it difficult for the sludge to flow down to the side drain for removal via the bottom purges).

It is advisable to have two opposing purges and to perform regular manual cleaning with internal hoses. This keeps the lower plate clean. For this purpose, hand or head access points should be provided at the level of the lower plate, positioned opposite each other to allow for hose cleaning of the entire plate.



As we can see in the previous figure, showing the sludge deposited on the lower plate (which can cause it to overheat), the upper plate is wet (it cools down), and we can see that the boiler is not completing combustion correctly. The flame penetrates the tubes and goes out, causing energy losses due to unburned gases.

We can see that we have installed two opposing bottom purges and cleaning plugs.

In summary: vertical boilers are cheaper, but generally have poor efficiency. It's important that the combustion chamber is tall enough to prevent the flame from penetrating the tubes.

The filter system can be dry or a system of pipes with water circulation (the problem with the latter is that if the chemical treatment produces sludge, the pipes can burn out when clogged with sludge if they don't have sufficient slope and the purges don't remove it).

To prevent sludge, the water must be softened (the salts that cause precipitation, generally calcium and magnesium bicarbonates, must be exchanged for sodium) or these salts must be removed with reverse osmosis (or by external chemical means).

AIR AND CHIMNEYS IN WOOD-BURNING BOILERS

In wood combustion, the air intake due to the chimney draft or the induced draft fan controls the combustion process. Since the amount of wood present is much greater than what is being burned instantaneously on the grate or grates, the combustion rate depends on the amount of air that comes into contact with the wood. **Similarly, combustion is stopped by completely cutting off all contact between the air and the wood.**

This last operation is very important when it is necessary to completely stop combustion due to a low water level.

When closed in these cases, air inlets must be very airtight.

Forced draft fans or air inlets below and above the grille depend on the negative pressure in the home (generally around -3 to -10 mmWC) and the primary, secondary, tertiary, etc., air fans.

Generally speaking**, the primary air under the grate (and secondary air) for combustion is adjusted according to the steam demand (regulated by the steam pressure)**.

Induced draft (chimney flue gas management) is controlled by the negative pressure in the combustion chamber (although this isn't always the case, as there are other alternatives).

In these other cases, different alternatives are adapted to each specific situation.

It is very important, then, before analyzing all types of wood-burning boilers, to explain how the combustion gases are carried to the chimney and how the

combustion air (primary and secondary) enters, because this largely defines the behavior of wood-burning boilers.

Although they all have in common **that the combustion chamber is under negative pressure** (that is, below atmospheric pressure, negative gauge pressure, so that gases do not escape through the wood loading inlets, sight glasses, ash pan covers, etc.).

This negative pressure is generally measured in millimeters of water column (mm w.c.) or millibars (1 mbar being approximately equivalent to 10 mm w.c.).

To measure this depression (or pressure, if present), a U-shaped tube with a diameter of several millimeters (for example, 10 mm) can be used. The transparent ends, made of glass or plastic, should be 300 or 400 mm long, with one end open to the atmosphere.

The other end should be connected to a copper pipe or similar (for example, 1/4" or similar), which should be connected through a well-sealed hole to the flue or chamber being measured. If a good seal is not possible, the copper pipe should be inserted into the chamber so that it is within the chamber being measured.

The U-shaped tube should be filled with water (with a few drops of alcohol and, if desired, a small amount of color dye, ink, or similar substance).

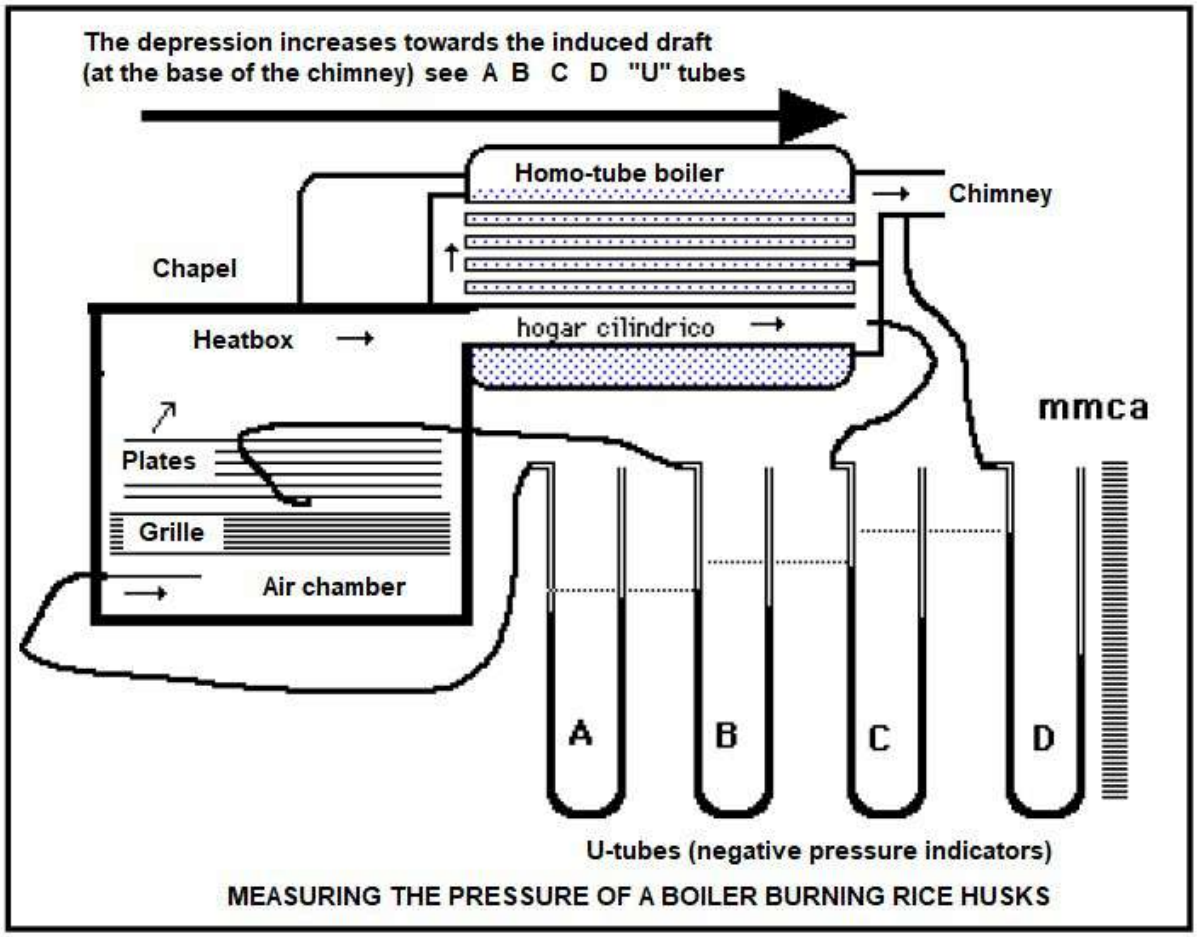
The end connected to the boiler, if there is a vacuum, will try to "suck" the water towards that end (it is actually the atmospheric pressure that "pushes" the other end, because its air pressure is greater than the chamber under vacuum), if there is air pressure in the chamber, the effect is the reverse.

The difference measured between the parallel part of the "U", in a vertical form (like a "plumb line") measured in millimeters with a ruler or meter) is the depression (in mm.c.a.).

In a combustion chamber, the draft will generally be -4 mm to -10 mm, but as we approach the chimney or induced draft, the depression increases (there is more "vacuum," meaning greater draft).

When the draft is natural, this depression is generally low (at the base of the chimney it can be from -10 mm to -20 mm, if the chimney is taller and the flue gas temperature is higher).

With an "induced draft" fan, it can be much higher, with the pressure at the fan inlet varying from -50 mmWC to more than -250 mmWC, depending on the type of fan, revolutions per minute, rotor diameter, etc., and how the air intake in the combustion chamber is regulated, or the penetrations due to leaks in the smoke box seals).



MEASURING THE PRESSURE OF A BOILER BURNING RICE HUSKS

As we can see in the graph above, the depressions increase towards the chimney flue (natural or fan induced).

1-Natural Draft in the Chimney:

Natural draft, as the name suggests, is the **"vacuum" that the hottest gases tend to create at the base of the chimney** as they travel through the flue (in reality, it is atmospheric pressure that pushes the air into the combustion chamber as the hottest air moves vertically through the chimney).

Since air decreases in weight (density) as it heats up, air in a boiler room might weigh about 1.3 kg/m³, but when heated to the boiler outlet temperature or chimney inlet temperature, it drops to about 0.525 kg/m³ at 400°C 752°F, although the chimney temperature is generally between 250°C 482°F and 350°C 662°F in naturally draft boilers.

The draft is equal to the difference between the weight of a volume of atmospheric air equal to that of the chimney and the weight of the hot gases it contains. Therefore, the taller the chimney (assuming the gases don't cool down and the chimney diameter is adequate), the greater the draft at the base of the chimney.

This draft is regulated in the chimney by means of a butterfly valve or by introducing cold air from the outside, in order to maintain adequate negative pressure or draft in the combustion chamber.

It's important to remember that the volume of gases needs a cross-section in the chimney to pass through. If the chimney becomes clogged and this passage narrows, the boiler loses draft and combustion is insufficient (the boiler's steam production capacity decreases).

The primary and secondary (or tertiary) air intakes are regulated along with the draft, by means of butterfly valves or dampers, located under the ash pan, above the grate, etc.

We can say that for a 10 m high chimney, when the gases have an average temperature of 250°C (485°F), the theoretical draft at the base is -5.4 mm w/w. If we double the height to 20 m, the draft will double, or -10.8 mm w/w.

The same can be said of the temperature: if we increase it to 300°C (662°F), in both height cases we will have -6 mm w/w and -12 mm w/w.

However, if the chimney cools down in winter to 150°C (302°F), the draft drops to -3.8 mm w/w and -7.6 mm w/w.

These theoretical values are what we would obtain if we closed the air intake to the boiler (and there were no other air leaks). At that moment, an instant before the temperature in the chimney drops, the "theoretical draft" occurs.

However, when we open the primary and secondary air intakes, the "work" of "circulating" the air and then the gases through the different sections of the boiler (where there are restrictions, such as the grate, tubes, regulators, etc.) causes a "restrictive work" to occur. This results in a loss of part of the theoretical draft, and we obtain the "actual draft."

That is, the draft we will measure in the combustion chamber (there is also energy or work expended in the circulation of the gases themselves, energy that will later be used to raise the gases to the atmosphere).

Conclusion:
If the chimney is low, has a small cross-section (meaning more air is expended to overcome the lack of cross-section), or the gases cool down, the draft will be weak, resulting in poor combustion and a slow response from the boiler (to increased steam production).

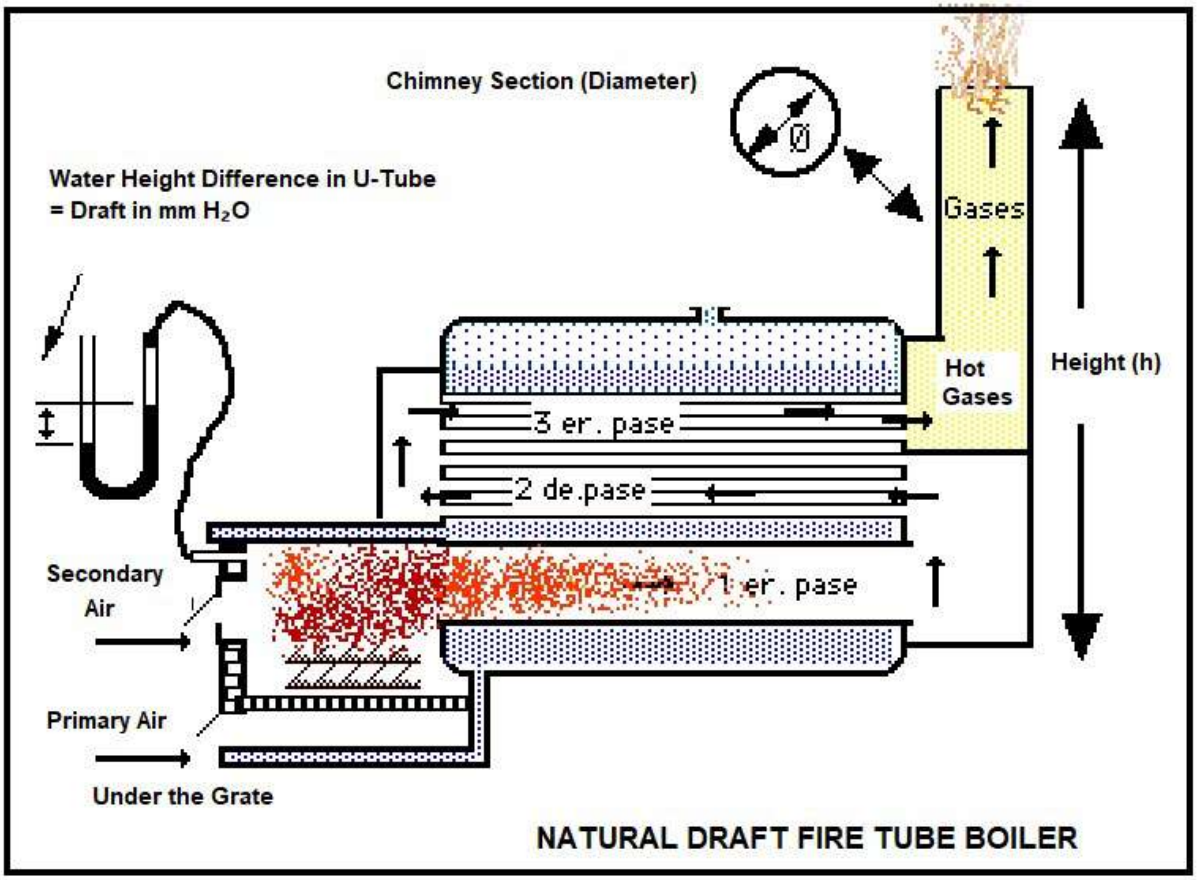
Especially when burning wood with high moisture content, a good draft is necessary, as it requires more air than dry wood, and the firebox is usually loaded with more wood to compensate for the lack of combustion.

Therefore, the chimney must have the appropriate cross-section (diameter), height, and insulation against the cold winter winds (which cool the gases in the chimney section).

In natural draft systems, primary and secondary air generally enter through the negative pressure in the home (that is, it is not "pushed" by a fan, but rather "drawn" by the negative pressure in the home), so the amount of air that enters depends on the "opening" of the air inlet and the negative pressure in the home (the greater the negative pressure, the greater the "force" for the air to enter from the boiler room).

This is how the amount of combustion is regulated, since the amount of wood inside the boiler remains constant. The amount of combustion or fire depends on the amount of primary air (under the grate or firebox in some cases) and secondary air (the secondary air is the air that enters above the grate.

Or in many cases, the excess air from the grate itself, which is used to "finish" the combustion started by the primary air, which also has an excess, that of the grate, often sufficient for complete combustion).



This highlights the importance of the chimney's dimensions, both in height and cross-section, and to prevent the gases from cooling down.

It also emphasizes the need to prevent air from entering through leaks in areas not essential for combustion (loading ports, cleaning ports, firebox linings—both refractory and pipe—flue boxes, chimney base, etc.).

In some cases, the primary air can be forced in by a fan (always maintaining negative pressure in the combustion chamber). In this scenario, the negative pressure in the combustion chamber is kept constant, and the amount of air forced in by the primary fan is varied.

2- FORCED DRAFT (or “INDUCED DRAFT”).

Natural draft boilers do not have a strong draft due to limitations in chimney height and cross-section, and the need for high flue gas temperatures. This results in a loss of efficiency, since the hot gases carry away the heat that could be used to improve performance.

Natural draft boilers generally have one or two gas passes, such as single-pass vertical boilers, two-pass fire-tube boilers, or two-pass water-tube boilers (older sectional boilers with semi-horizontal tubes).

Since boilers must maximize the use of the heat produced, minimizing their size (making them more efficient with less material) requires increasing the number of gas passes, installing heat recovery systems (such as economizers, i.e., feedwater heaters or heaters for other uses, or recovery heaters to heat the combustion air), or increasing the response time to changes in steam consumption.

All of this means that natural draft is no longer sufficient, so forced draft (the suction and propulsion of hot gases by mechanical means) is used.

The term “forced” draft can refer to a series of systems in which the air is forced (as in the old case of pressurized boiler rooms, generally applied in ships, pushing the air and preventing the gases from escaping into the boiler room) or by sucking the gases out by mechanical means (fans) or by means of air or steam inductors.

As in the case of locomotives, where a draft is created with a steam injector as if it were a "venturi," that is, a "jet" of steam is discharged into a narrower section of the chimney through a nozzle.

This steam "drags" the gases, making them gain speed, which forces an increase in the capacity of the chimney and therefore the "draft" at its base, as happens in movies where steam "locomotives" appear; when they are working hard, the chimney is seen with very overloaded smoke. The steam that is generally used is from the discharge of the machine's own cylinders or pistons, so as not to waste extra steam, since the water in the steam is not recovered.

But, in our case, we will generally call it **“induced draft” when a fan (extractor, mechanical, driven by an electric or steam motor: turbine or reciprocating machine) placed between the boiler and the chimney (or between the heat recuperators and the chimney), “sucks” the gases and “pushes” them to the chimney.**

The combination of induced draft and forced air (or forced air: secondary and tertiary forced air under the grate) allows for heat recovery from the flue gases, facilitates the supply of all combustion air under all conditions, and ensures the use of all air passes and heat recovery systems, **maintaining suction in all sections to prevent gas losses and emissions into the boiler room.**

This is especially crucial for wood-burning stoves, as the wood must be loaded through an inlet exposed to the boiler room, and because wood fumes can be polluting and even toxic (the presence of CO—carbon monoxide—which is toxic upon accumulation).

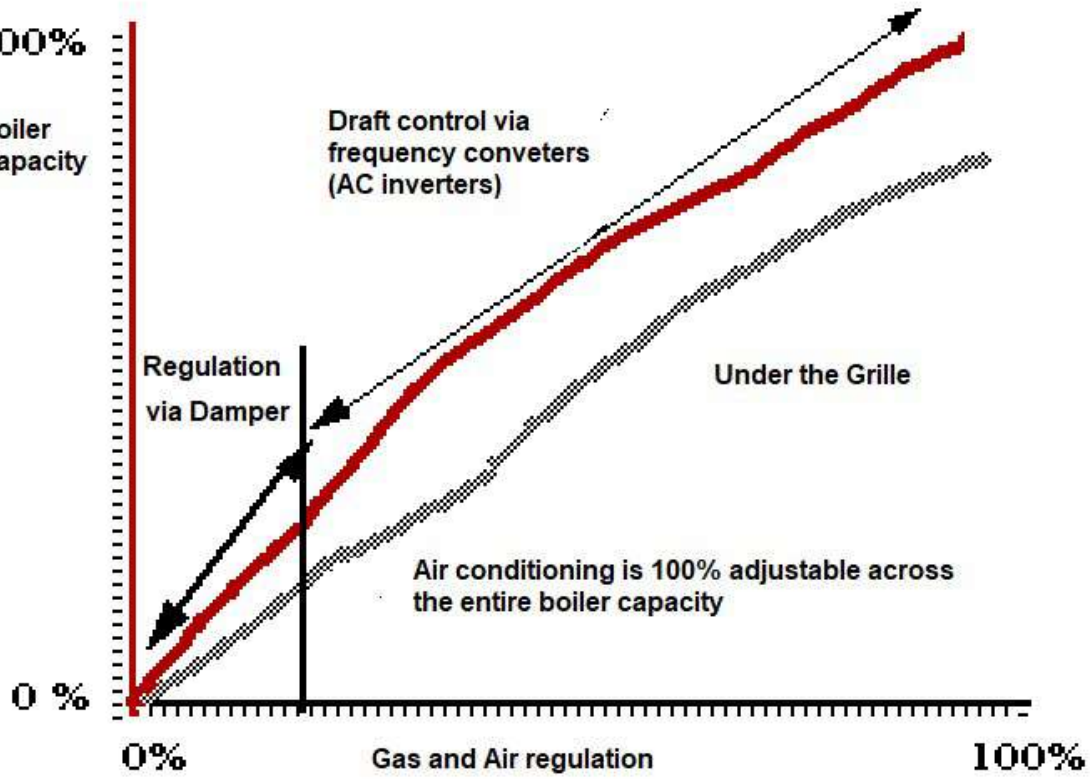
In wood-fired boilers, combustion gases must not be allowed to contaminate the premises where personnel work (due to the CO that may exist in some circumstances or stages of combustion, with other "unburned" gases that may be harmful to health).

Generally, the "induced draft" (chimney fan) automatically (or manually) maintains the negative pressure in the combustion chamber (from approximately -4 mmWC to about -10 mWC), varying its capacity by means of a gas valve (shutters or butterfly valve at the fan inlet), or by varying the speed of the fan rotor (by means of a mechanical variator or an electronic frequency variator of the alternating current that powers the fan motor, thus varying its rotation speed or rpm).

Although we recommend combining modulating "shutter" control with motor frequency converters, because the converters (AC inverters) alone do not regulate from 0% to 100%, but rather in increments that can be 30% or more, making it difficult to accurately regulate both the air below the grate (primary) and above the grate (secondary or tertiary), or the induced draft in the chimney.

This allows maintaining combustion chamber negative pressure at different loads, and what is varied to increase or decrease combustion are the primary, secondary, and tertiary air fans. The induced draft follows the flow rate of these fans, maintaining the preset negative pressure in the

combustion chamber.



When the boiler only has "induced draft," combustion capacity is achieved through the negative pressure in the combustion chamber created by the induced draft. The draft is increased or decreased according to the combustion air requirement. This is complemented by the regulation of primary and secondary air intakes via the intake valves.

"IN "INDUCED DRAFT" SYSTEMS, THE WOOD LOADING INLET OR THE SIGHTS SHOULD NOT BE OPENED WHEN THE INDUCED DRAFT IS OFF."

If the induced draft is off, the hearth is full of "half-burned gases," which, when an air inlet (viewing windows or wood loading door) is opened, allows oxygen to enter and mix with the unburned gases, potentially causing a hearth explosion and/or a "flame" to shoot out towards the person who opened the viewing window or loading door. THIS IS VERY DANGEROUS!

In some cases, **it is advisable to install a safety system, an interlock, that prevents the opening of the wood loading door if the induced draft is turned off** (especially when burning sawdust).

It is always advisable that, with the induced draft turned off, a small amount of natural gas venting be allowed through the draft fan. This is for the default "sweeping" of the gases.

A slight negative pressure in the combustion chamber prevents gases from escaping into the boiler room.

This especially true when the primary, secondary, and tertiary air intakes do not close and seal properly or shut off if forced, including the induced draft. This situation can occur when the steam is cut off due to high pressure, as it should be, but some air continues to enter, or if the induced draft shuts off for any other reason.

This default "purge" ensures that gases such as CO do not escape into the boiler room, although this small air intake causes a small amount of vaporization, meaning that the boiler does not "shut down" completely; it continues to generate steam and build pressure if there is no consumption, but this generally does not represent a problem unless there is a significant drop in pressure.

It's also important to consider that the wood loading systems should be as airtight as possible as possible while the wood is being loaded into the combustion chamber, since the incoming air doesn't contribute to combustion (it's air that enters and "steals heat").

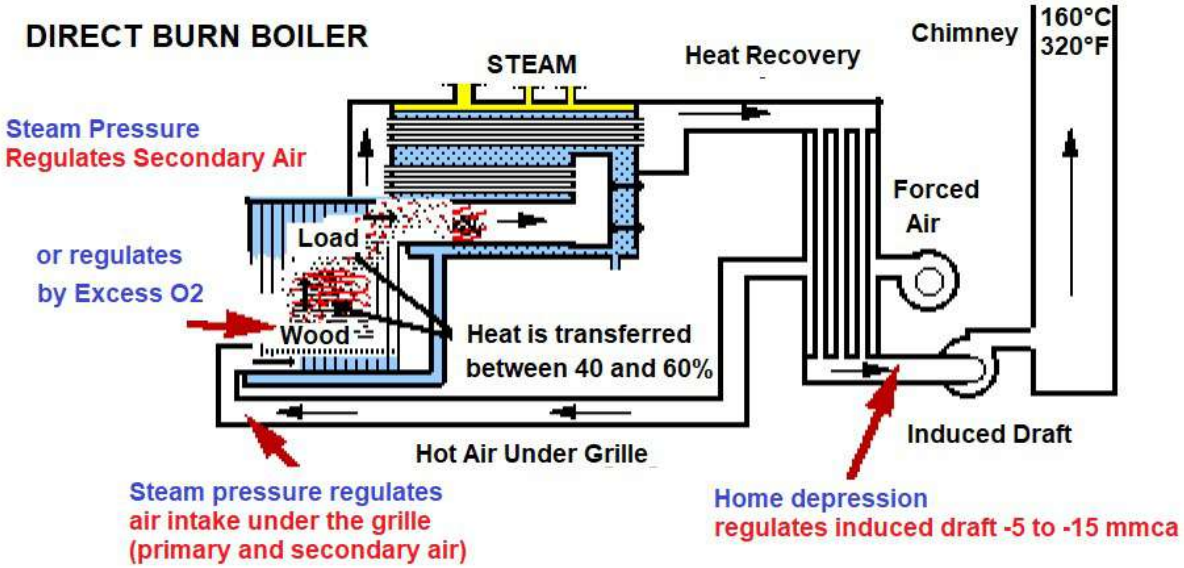
Air exiting through the chimney accelerates the chimney's induced draft to achieve the desired negative pressure, but even so, a lack of negative pressure affects combustion and can lower the boiler's steam pressure (air doesn't enter the combustion zone, i.e., between the wood on the grate; there's an excess of air that consumes heat, etc.).

But the most objectionable aspect of these systems is that they expose the operator to a combustion chamber explosion (which can be caused by a mixture of gases with incoming air, or by any other cause, or simply by the explosion of a chamber tube due to poor circulation or insufficient wall thickness caused by corrosion from combustion over years of use).

Although these "double-lid" or "double-door" magazines, with their doors interlocked, must be constructed in such a way that the upper, or outer, lid locks into place when the lower loading lid opens, otherwise, if this outer lid opens during an explosion, the operator will not be protected.

Some wood-burning boxes have an outer loading lid that tends to jam in the event of an explosion. These boxes typically have two compartments: one above the outer lid where the wood is pre-loaded and then transferred to the intermediate chamber. The outer lid is then closed and locked against a sturdy frame, allowing the loading lid directly into the combustion chamber to be opened.

These lids, which are in contact with the combustion chamber, are usually made of special cast iron, and both are operated pneumatically or hydraulically.



Induced draft is generally controlled by a combustion chamber pressure sensor (which maintains the pressure between -4 mmWC and -10 mmWC), and forced draft is controlled by pressure switches connected to the steam pressure.

There is also a high-pressure steam cutoff switch for both forced and induced draft (blocking the forced draft fans to prevent positive pressure in the combustion chamber; that is, the forced draft can never ignite if there is insufficient vacuum in the chamber). See below: Pressure Switches.

CHAPTER 5: Operation Part 6

ASHES AND SPARKS DRAG

The entrainment of ash and embers (burning wood fragments or "coals") can occur under certain conditions, especially when there is induced draft (and the possibility is increased by having "forced" air under the grate), when steam production is increased, or when the boiler is operating at a high combustion rate.

When the boiler load (degree of combustion) is high, generally, in either system (direct combustion or gasifier), entrainment of material (ash and burning wood fragments, embers) occurs due to the high air velocity between the grates and the rollers that form the combustion bed.

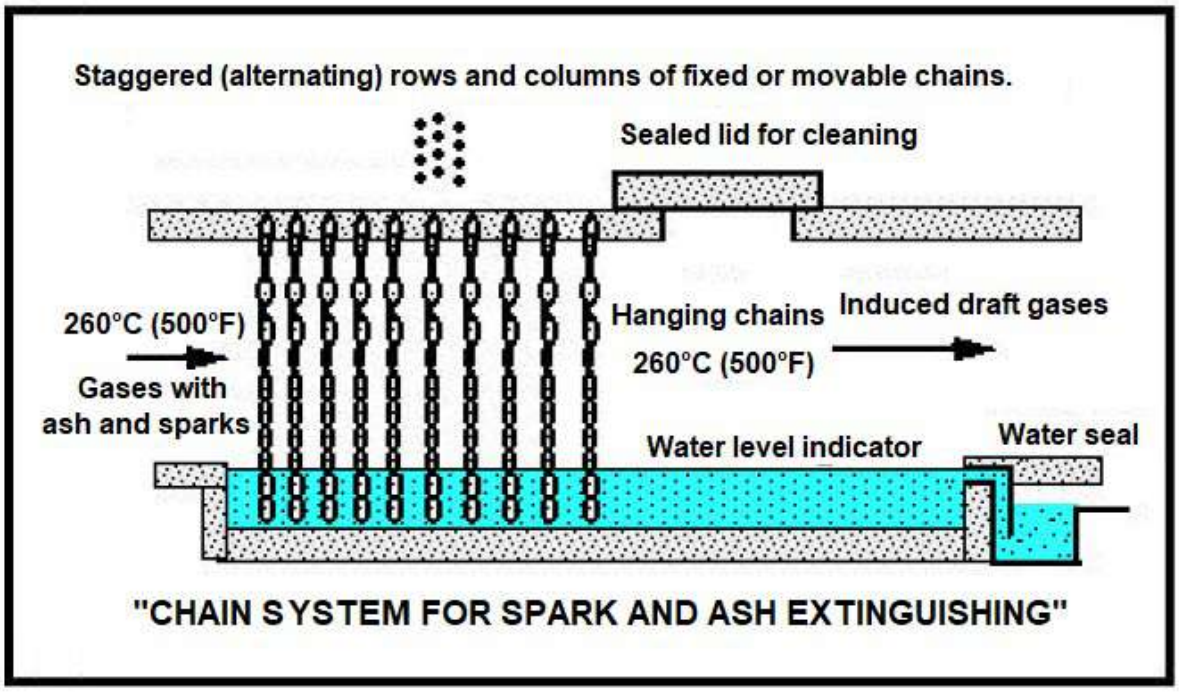
This is more serious the more ash the firewood contains (which increases with husks), and in the case of husks (like rice husks, where the ash content is over 20%), the more ash is carried away.

Ash is an environmental pollutant (especially when it is silica, like rice husks used as fuel), **but burning embers can be a fire hazard near boilers (especially in factories with flammable materials nearby).**

To prevent the carrying of ash and embers, the stoker's operation of the boiler and the quality of the firewood are fundamental, but this is generally not enough in some cases, **so it is necessary to install elements that "trap" the ash and embers (in this last case they call it a "spark arrester", but we will not make a difference).**

The most basic thing is to make a chimney base and a "low speed" chimney; the second would be to put in front of the induced draft a "tunnel" with a lower pool with a certain level of water (which has to be cleaned every so often) and with chains "hanging" from the top, almost touching one chain with the other and placed in a "staggered" pattern (that is, alternated, which force the gases to collide with the chains).

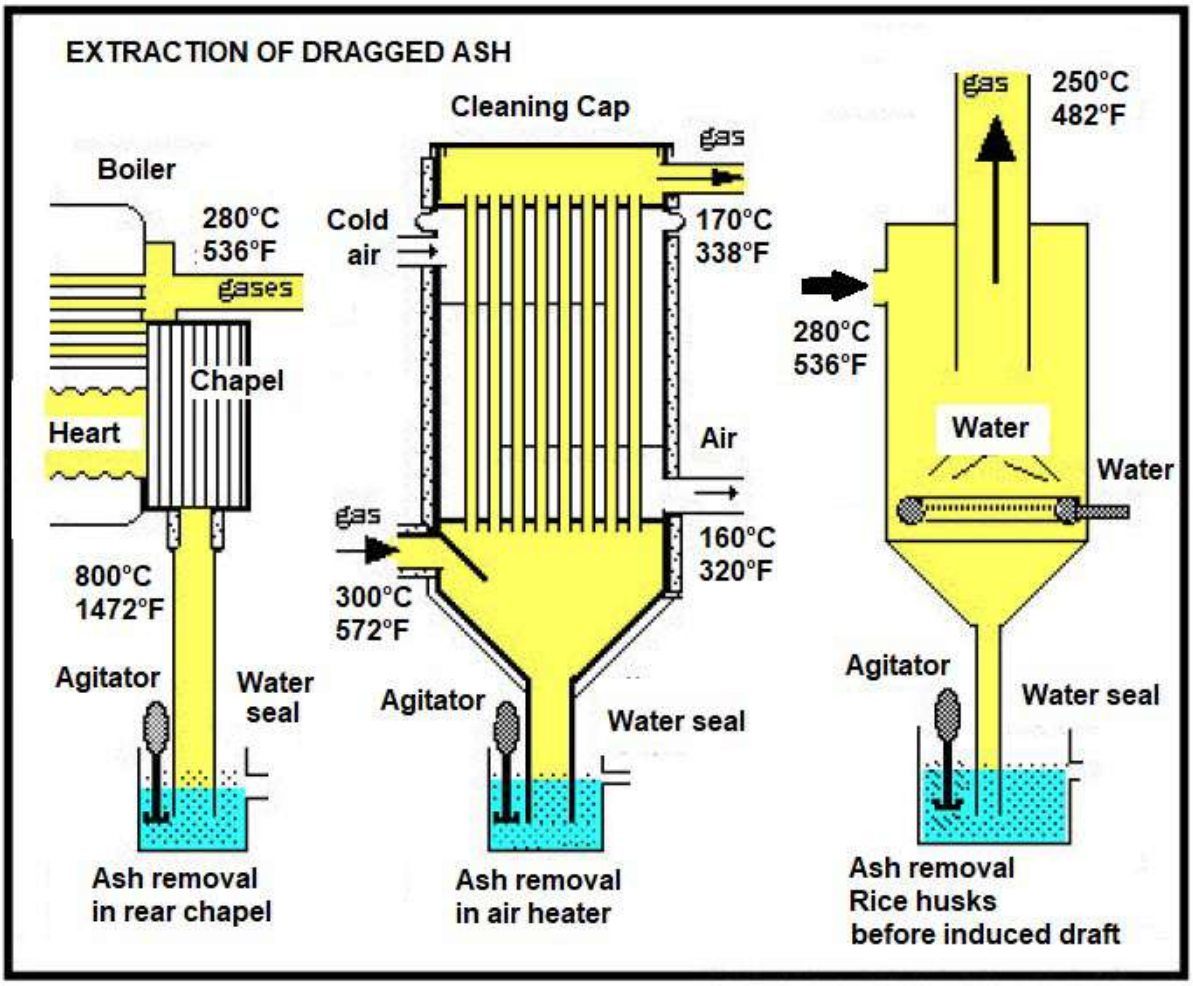
The dragged materials hit against the links, the chains being placed in several rows and columns (alternating in a “staggered” pattern); if the chain system has the possibility of a manual movement every now and then, all the better, to “detach” the material stuck to the chains).


Staggered (alternating) rows and columns of fixed or movable chains.
Sealed lid for cleaning
260°C (500°F)
Gases with ash and sparks
Hanging chains
260°C (500°F)
Induced draft gases
Water level indicator
Water seal
"CHAIN SYSTEM FOR SPARK AND ASH EXTINGUISHING"

To all this, the next step is to place between the induced draft and the last recuperator: a multicyclone (small cyclones in parallel, high speed, made of abrasion-resistant material, which discharge the ash into a common sealed chamber; the problem with this system is the high cost).

In the case of rice husks, I designed a "low-speed" system with a central bottom section using a water spray to trap the particles (this has worked very well, but it must be carefully designed, and the "abrasion" zone must be made of a "hard" and replaceable material; the water only "wets" the lower zone, where the particle density is highest, with the material separated by the water "falling" into a "water seal" with the cleaning basin running).

The gases should not be cooled with water, as this would prevent them from rising when they exit the chimney due to insufficient temperature. They need to rise to disperse into the atmosphere and not remain above the discharge area, since these gases have a very low oxygen (O2) content, a high carbon dioxide (CO2) content, and may contain carbon monoxide (CO) – toxic – and other unburned gases that are harmful to health. This concept should be considered with any fuel.



In addition, separators can be installed within the smoke boxes themselves (taking advantage of the reduced gas velocity and change in direction, by placing a discharge duct with a water seal and a cleanable basin at the bottom).

Care must be taken because the first part of the duct is in contact with gases at over 800°C, so the first part of the duct must be refractory and insulated. Ideally, the part in contact with the water should be made of stainless steel, or the entire duct if long-lasting durability is desired.

One of the problems with all separators is sealing the material collection "box" (ashes and incandescent matter). I prefer that these seals be made with "water seals" because they are more effective and also extinguish any sparks that fall (although they are usually of the "dry" type, which, because their lids do not close properly, causes air leaks that reintroduce the separated material into the induced draft system).

In general, **it is necessary to prevent the induced draft fan from being impacted by ash (there is abrasion, the case of rice husks is very severe), so it is advisable that the fan rotor and some areas of the fan housing be protected by harder material** (whether by layers of chrome-nickel welding in the most damaged areas, or by making "beads" that separate the "vein" of gases from the impact on the surfaces).

In the case of husks, when the ashes have a high silica content (as in the case of rice), preventing them from escaping through the chimney is very important, since this silica, when inhaled, can cause lung diseases (such as silicosis or others).

DIRECT-BURN ROLL LOADING SYSTEMS

One of the concerns to consider with direct-fired boilers is the method of loading the logs. Logs up to 1,200 mm (4 feet) long and up to 250 mm (10") in diameter are acceptable.

During boiler operation, if the boiler operator is exposed to the combustion chamber, they are at risk of a furnace explosion, but more importantly, they are exposed to the "bursting" of a furnace wall tube or grate support tube (although if the grates are made of cast iron, the explosion and discharge of water and steam usually occurs in the ash pan).

Historically, locomotive or ship boiler operators, when coal-fired, were exposed to the risk of explosions from the tubes against the burning coal mass (expansion of steam from its own superheated water plus the added

heat from the incandescent mass itself). Clearly, in a small boiler, the loading door is a simple opening (like a hinged door, see previous photo).

Solving how to isolate the boiler operator from exposure to a furnace or pipe explosion is a complex but not impossible problem.

In the case of small, side-loading boilers, the boiler operator is not only exposed to an extremely high risk, but also, each time the rollers are loaded, air enters that does not participate in combustion. This causes losses due to the incoming cold air being heated, "stealing" heat along with the flue gases.

Furthermore, it affects the boiler's performance, as it causes a loss of negative pressure in the furnace, preventing primary combustion air from entering the combustion chamber and thus causing the boiler to lose pressure.

There is an additional increase in loss due to the effect that the induced draft increases if it is with "automatic depression" because it does not detect the "set-point" vacuum, thereby increasing the losses due to hot chimney gases since it brings in more cold air that does not provide oxygen to the combustión.

BOILER EXPOSED TO A FIRE EXPLOSION
THE OPEN TOP COVER EXPOSES THE BOILER
AND HAS NO RETAINING LATCH

What should not be done is to expose stokers to explosions in medium and large boilers, as these boilers magnify the potential for explosions due to the large volume of water they can release (especially since they generally operate at higher pressures).

In these medium and large boilers, the problem of how to prevent stokers from being exposed to a furnace or tube explosion with high steam expansion has already been solved; there are solutions and ways to protect stokers, but unfortunately, these are not always implemented.

The loading "gates" for safety (for top loading) have two loading stages: a pre-loading zone where the rolls are stacked with the upper gate closed (which opens towards the combustion chamber, so that in case of an explosion it tends to close),

then an intermediate chamber that is loaded with the rolls from the "pre-loading" stage, but which has a high-temperature steel gate that isolates it from the combustion chamber.

This loading gate only opens when the pre-loading gate is closed and also closes as a lock in case of an explosion in the combustion chamber.

The great advantage of this double safety damper is not only that it protects the stoker in case of a furnace explosion or a chimney pipe failure, but also that it prevents air from entering through the dampers, so there are no losses due to the entry of "parasitic" air and the furnace negative pressure is not lost (which maintains the induced draft with the regulation of the "set-point" - the set point of the furnace negative pressure - which does not distort the operation of the boiler or produce losses).

Let's look at some diagrams of a "safe loader."

There is a pre-charge that the operator prepares. While the charge that has moved from the pre-charge to the loading area is sealed, no air has entered because the bottom cover is closed.

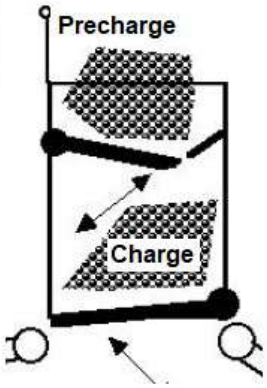
While the charge is being discharged into the combustion chamber, the pre-charge cover remains closed, preventing the stoker from being exposed to a combustion chamber explosion, while the operator prepares the pre-charge.

Once the charge is discharged into the combustion chamber, the charge cover is closed. Once closed, the pre-charge cover can be opened, again preventing the operator from being exposed and allowing air to enter the combustion chamber.

This system has four fundamental elements: the operator is not exposed to combustion explosions; no extraneous air enters (air that does not contribute to combustion and "steals" heat, escaping through the chimney as useless "excess air"); it does not destabilize the induced draft since the combustion chamber's negative pressure remains unchanged; and it allows for continuous loading of the logs into the firebox.

By simply observing the figure below, the reader will understand how the system works.

OPEN



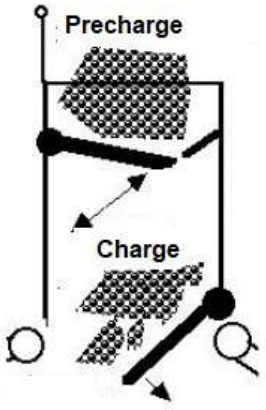
PRECHARGE

Precharging is done as soon as the upper door is closed.

When this occurs, the lower door opens.

CLOSE

OPEN



CHARGE

Charging is done with the upper door closed (it protects against stray air). Charging is almost continuous.

However, we must acknowledge that many boilers that, due to economic constraints, have not been fitted with safe "discharge dampers" or "chargers" often have unsafe chargers with a double cover.

But these do not provide operator protection, since the upper damper opens in the event of an explosion due to the pressure of the gases and steam against the damper, which opens upwards, not downwards as in a "safe" damper.

What is often overlooked is that a "safe charger," by preventing the entry of extra air and maintaining negative pressure, produces energy savings. The cost of the "safe charger" is recouped in months through fuel savings.

As seen in the photo above, a pipe "under the grate" (the grate support in a direct-fired boiler) is clogged or practically clogged with sludge.

This occurs in almost every boiler if the sludge isn't hosed out once a year.

Sludge in the boiler indicates that the water treatment system has failed in the water softeners, allowing hard water to enter. It also suggests possible contamination of the condensate returns with hard water.

Proper water treatment transforms hard water into sludge, which should be removed through the boiler's blowdown valves.

The sludge enters and circulates through the flue pipes, which is natural, since the flue pipes are connected to the lower part of the boiler, the area where the sludge settles.

Because the grate tubes have a slight incline, the sludge, following the flow of the circulation, cannot reach the upper collector that supports the grate at the top, and instead settles until it clogs the tube.

It does not exit through the blowdown valves, since the blowdown valves are located in the collectors, in the manifold tubes at the end.

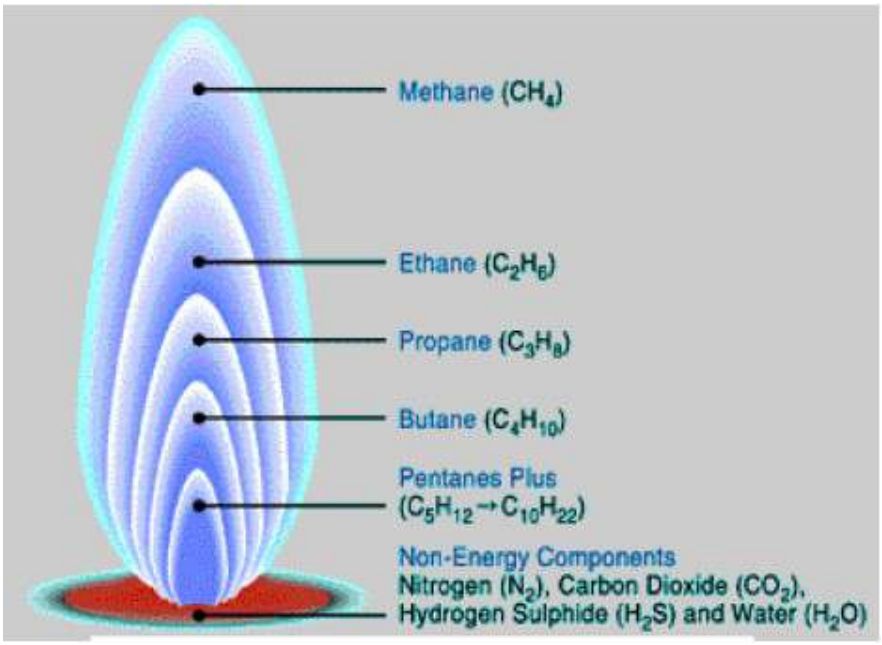
The sludge enters before these valves and settles, clogging or nearly clogging them, thus preventing circulation.

A pipe with poor or no circulation is almost certainly prone to a "burst" due to overheating of the metal and the force of the water and steam pressure in the boiler. The loss itself, plus the expansion of the water against the combustion chamber, exacerbates the force of the explosion.

This demonstrates the danger posed by an "unsafe" charge system that exposes the stoker to direct contact with the combustion chamber during charging.

CHAPTER 5: Operation Part 7 Natural Gas Burners [1-2-3 of 5 points]

NATURAL GAS BURNERS



The information provided in this chapter on natural gas should be taken with caution and at the user's own risk, as it does not correspond to any particular regulations, but rather describes in a general way: information and personal experience, therefore its use is not the responsibility of the author, CWT.

The possibility of burning natural gas is already a reality (Natural gas has been in use in Paysandú since 1999 at ANCAP and in other industries since 2000). It has also been used in southern Uruguay since 2003. The benefit will not only be economic, since, for the same calorific value, it could be the cheaper gas (depending on the fuels being compared and the market situation), but also that gas combustion, if properly installed and adjusted, has fewer maintenance problems (but the system must be constantly monitored, especially the safety system and combustion results).

Since there will be no need to work with liquid fuels and soot will be a thing of the past (not quite, if there is a lack of air and a bad mixture, a very insulating soot can be produced without visible "smoke", which will be observed by an increase in the temperature of the chimney gases, as the transfer surfaces are insulated, the presence of CO and a darkening in the expelled gases will be noticeable, this soot can be expelled through the chimney and be noticed by the deposit on roofs and patios).

Supposedly, there will be less pollution due to the lower production of CO2 (carbon dioxide, one of the gases that cause the "greenhouse effect"), since natural gas contains more hydrogen (H) and less carbon (C). However, being a fossil fuel, it will still be polluting.

Nitrous oxides (nitrogen from the air and fuel, when oxidized by high temperatures, forms NOx, nitrogen oxides) will be produced in smaller quantities during combustion, and sulfur will supposedly be almost entirely eliminated in adequate supplies, thus reducing pollution from SO2 (sulfur dioxide). Both contribute to acid rain along with CO2, although SO2 is more corrosive, even highly irritating or toxic to living beings.

This will be beneficial if the gas burners are properly adjusted, without excessive air (generally no more than 15% excess on the high side and 30% excess on the low side) or insufficient air, or other combustion problems related to the burner or its adaptation to the boiler (which could cause unburned gases).

BUT BE CAREFUL! There will be a greater chance of accidents involving the fuel if things aren't done correctly.

For example: a gas leak into the boiler room environment could ignite violently simply by turning on the light (boiler rooms must be very well ventilated), or a burner purge could cause a combustion explosion (or other malfunctions).

The presence of CO due to incomplete combustion (since combustion cannot be adjusted by eye; there could be insufficient air, inadequate air-gas mixture, or a cold flame, resulting in incomplete combustion) can be a problem, as CO is a colorless and odorless gas that is toxic when accumulated or present in excess in an environment.

We only realize it through the symptoms: headaches, vomiting, dizziness, etc., which generally disappear upon leaving the contaminated environment (a boiler room or any other contaminated space). There are electronic detectors with alarms for detecting carbon monoxide. However, carbon monoxide (CO), at a certain concentration and exposure time, causes death (a very common occurrence in cars in cold countries, where closed windows and unventilated vehicles, often left in traffic jams, leave the engine running for heating. If the exhaust pipes leak combustion gas, rich in CO, when the engine is idling, and this enters the car, it poisons the occupants).

Here we must divide the problem into 5 points:

1- the problem of receiving the gas properly with all the necessary safety elements,
2- the burner must meet all the requirements for burning natural gas,
3- the boiler room must be adequate,
4- the burner must be adjusted using instruments,
5- the personnel must be carefully instructed and trained.

1- The problem of receiving the gas properly with all the safety elements:

The natural gas pipeline supplier (we will refer mainly to this), will supply a gas that is as “standard” as possible within the agreed conditions (that is, natural gas varies from supply to supply), since it is a composition of different gases in which carbon -C- and hydrogen -H- combine in different ways, forming gases whose carbon to hydrogen ratio varies and with it varies their capacity to react with oxygen, the calories they can give, the combustion rate, etc.

The predominant gaseous form will be methane, whose formula is CH4. It contains a high proportion of hydrogen relative to carbon (it is also called "swamp gas" because it is produced naturally by the decomposition of organic matter).

Furthermore, it is a colorless, odorless gas, slightly soluble in water, and highly flammable. The molecular weight of methane is 16, meaning it has a much lower density than air, which has an average molecular weight of approximately 27.

Supposedly free methane tends to rise in the atmosphere, or in a room, it will rise to the upper parts.

Natural gas cannot be liquefied at low pressures (like bottled gas, which is made up of heavier gases) at ambient temperatures (its temperature must be lowered to very low values so that the pressures at which it liquefies are not high in the containers).

For this reason, it is necessary to transport it through pipelines at high pressures (to increase its weight per unit volume). Transport can be carried out at pressures exceeding 70 kg/cm² and speeds of 40 km/h, so that the pipelines do not need to be very large, and the gas is pumped through them

using large gas compressors.

Once it reaches the site of use, the pressure will be lowered to an average value acceptable for the supply of the local network, being lowered even further at the final place of use, where the pressure will generally be relatively low (centimeters of water column: cm.w.c. or meters: m.w.c. or millibars: mb which is equivalent to 10.2 mm.w.c., in practice 1 cm.w.c. or 10 mm.w.c.).

As for natural gas, after its extraction from the wells, it must be prepared for use, in which condensable elements (hydrocarbons that condense under pressure), water and entrained solids are removed, the sulfur content is reduced, etc., depending on its composition.

For example, let's look at the composition of a natural gas:
Typical composition of a **natural gas** (% by volume):
Methane....CH4..... 88.1%
Ethane.....C2H6..... 4.90%
Propane...C3H8..... 2.30%
Butane.....C4H10..... 0.70%
Pentane....C6H12..... 0.10%
N2+O2.....1.40%
CO2.....2.60%
Supply Heat Value (MJ/m3) 39.6 Mj/m3
Relative Density (air=1)..... 0.643
Woube Index..... 49.4

Now let's look at the composition of natural gas in Paysandú Uruguay (November 1999)
Molecular Weight %
Methane CH4 16.041 90.984%
Ethane C2H6 30.067 4.083%
Propane C3H8 44 1.196%
N-Butane C4H10 N 58.118 0.330%
Isobutane C4H10 I 58.118 0.210%
Isopentane C5H12 N 72.144 0.091%
N-Pentane C5H12 I 72.144 0.080%
N-Hexane C6H14 86.169 0.116%
Carbon Dioxide CO2 44.01 1.967%
Nitrogen N2 28,016 0.935%
Relative density (air=1).....0.624
Density (weight per volume)... 0.76 Kg/m3
P.C.S. 9,402 Kcal/m3 or 12,292 Kcal/Kg.
P.C.I. 8,494 Kcal/m3 or 11,105 Kcal/Kg.
Woobe Index.....49.8

To detect leaks by smell, an odorant (generally mercaptans, sulfur-based compounds with a typically very strong and unpleasant odor) is injected at the distribution terminals.

This will make any leaks into the environment detectable by smell. (This is required by law to prevent accidents. The odorant is typically injected at approximately 3 mg/m³ at the point of consumption and no less than 5 mg/m³ at the injection point, depending on local regulations. Its odor must be noticeable in the presence of a leak.)

In Uruguay, the Argentine standard NAG 100, which allows for the detection of natural gas concentrations of approximately 0.2% in the air, is currently in effect (2004). Control of this standard is the responsibility of URSEA (Regulatory Unit for Energy and Water Services).

Electronic gas sensors are also available and must be installed in areas where a certain volume of gas is handled and where, for safety reasons, gas accumulation must be prevented to avoid the risk of explosion.

These electronic devices generally work in various ways, but they don't detect odor; rather, they detect the physicochemical properties of the gas. The oldest of these are called "explosimeters."

These devices operate based on the combustion of any gas present in the environment. This combustion takes place inside a "cell" containing a catalyst. The device detects the heat energy released when a given proportion of the gas combusts with oxygen from the air. The amount of heat indicates the proportion of gas present. More modern devices analyze other properties of the gas.

Gases "explode" within a certain proportion with air; a small electrical spark (like the spark from a light or flashlight switch), a mechanical spark (the impact of one iron tool on another iron or stone), a "static" spark (caused by the friction of two elements), or heat (since if it comes into contact with temperatures above 600°C 1112°F, it combusts) is enough.

In the United States, in 1999, the power plant at the largest auto assembly plant exploded, killing, injuring, and burning numerous workers.

This explosion occurred in a boiler that was shut down for inspection: a small leak of natural gas filled the furnace of a large boiler (in a room with several high-pressure boilers in operation). This gas, mixed with air inside the

furnace, for some reason ignited in an explosive combustion (spark, small light source, etc.). This disaster, at the end of the 20th century (a time of high technology), clearly demonstrates the need for caution when using natural gas.

Another case occurred in Uruguay in the late 1980s. A welder entered a large boiler (a water-tube boiler of a sectional boiler) while using a gas cylinder (supergas) for cutting with a blowtorch.

Even with the blowtorch off, a small leak began to fill the combustion chamber with gas until the mixture with air created an explosive mixture. When he used an angle grinder to grind the metal, a spark ignited the mixture, killing him.

Another case occurred in Uruguay at the end of 2003. Due to a lack of training of personnel by the company supplying a "dual" burner for fuel oil and natural gas, a "combustion chamber explosion" occurred after the first operation using heavy fuel oil. This was caused by a natural gas outage of only a few hours, when they attempted to restart the burner with natural gas.

The gas feed nozzles were clogged with fuel residue, slag, and concentrated fuel, which prevented the gas "ring" from igniting initially, causing a concentration of gas in the combustion chamber (perhaps increased by the release of gas from the fuel oil residue). When this gas ignited at the end of the main flame establishment period or earlier (either by the pilot light or by a fire in the deposited soot that was reignited during the purging process), it caused a violent explosion, seriously injuring those attempting to start the boiler with gas.

Unfortunately, there are many examples of this. With gas, we must be very careful when working in an area where it can accumulate (avoiding any leaks, keeping vents in good condition, sweeping with air or preferably working in an air current, avoiding the accumulation of gas in enclosed spaces).

A common problem is that boilers in buildings are located in lower areas (such as basements), so if fuel accumulates due to leaks (or, being lighter than air, rises and enters upper spaces), it can cause an explosion with the "demolition" of the building.

Boilers in general, and especially gas boilers, should be located in well-ventilated areas, with enclosures made of lightweight structures, so that in the event of an explosion, the building structure doesn't become like a grenade.

In other words, the explosion should be easily contained. Unfortunately, Uruguay has many examples of installations that are ideal for causing significant damage.

The leaner the mixtures, the more dangerous they are (the flame speed is very high) and the richer the gas, the slower they are (the flame speed is lower), meaning that there is a minimum value of gas to mix with air to "explode" and a maximum value above which, if we are with the mixture above a certain proportion, ignition no longer occurs.

Combustion Limits for Air-Gas Mixtures

Gas	Low%	High%
Hydrogen	4.0%	75.0%
Acetylene	2.5%	80.0%
Methane	5.3%	14.0%
Natural Gas	5.0%	14.0%
Town Gas	5.0%	37.0%
Propane	2.2%	9.5%
TLP	8.0%	36.0%

(TLP: tempered liquid petroleum gas)

As seen in the table above, methane and natural gas have almost the same limits, since natural gas is mostly composed of methane.
This table indicates that low percentages of loss in an environment can be very dangerous.

The other factor that determines a gas's combustion advantages and risks is its ignition temperature.

In the case of methane and natural gas, depending on the percentage of mixture with air, the approximate ignition temperature is:

% of GAS IN AIR	4%	6%	8%	10%	12%	14%
For Methane, °C	635	6375	642	648	659	670
°F	1175	1178	1187	1198	1218	1238
For Natural Gas, °C	632	612	611	612	613	617
°F	1169	1133	1131	1133	1135	1142

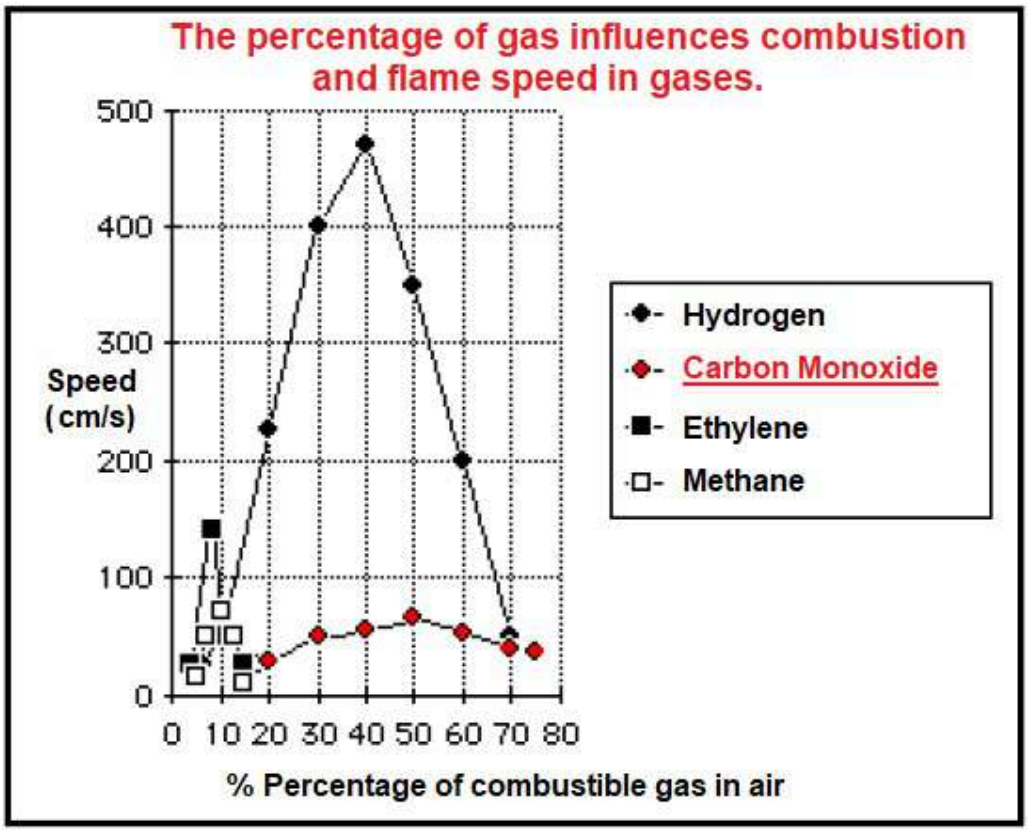
A temperature of +600°C (1112°F) can be produced by a static spark, a light switch being turned on, a broken incandescent lamp, a simple flashlight not

protected against explosion, or a simple metallic impact (iron, steel, cast iron, but there are special tools made of copper or other metals that do not produce sparks when struck).

Flame speed is very important, both for combustion in a burner and in an explosive mixture. Hydrogen is the element with the highest combustion speed. Since natural gas contains methane as its main component, which is very rich in hydrogen, it might seem that its combustion speed would be very high. However, this is not entirely true due to the presence of other elements.

The flame speed of typical natural gas in a Bunsen burner (an open burner) can be measured at approximately 300 mm per second (hydrogen is about 2830 mm per second). The maximum flame speed of typical natural gas occurs at 100% of the theoretical air required (or minimum air, approximately 9.8 m³ of air per m³ of natural gas, close to a "lean" gas mixture, i.e., 5% by weight).

In a tube, such as in the hearth of a fire-tube boiler, the velocities vary, see the graph below, in a 1" diameter tube (inside the fire-tubes, from 2" to 3", the flame is extinguished by cooling, so combustion must be completed before the gases reach and penetrate the fire-tubes).



The combustion rate is very important for flame behavior. It depends on many factors (the mixture, the percentage of air, the temperature, the composition, the shape of the combustion chamber, the pressure, etc.). The graph above shows flame or combustion rates in a 1" diameter pipe, which may vary as discussed.

As can be seen, hydrogen in a 40% air ratio has the highest combustion rate. The main component of natural gas is methane, so the combustion rate is similar to that of methane.

It is generally thought that natural gas (or wood gas as in a gas generator) will have a very high combustion rate, this is not the case, since the composition of the flame varies during combustion time, and the flame temperature also varies as it moves away from the burner (it increases and then decreases)

In liquid fuels like fuel oil (rich in carbon), the flames are very bright, accelerating combustion due to the catalytic effect of the incandescent carbon particles within the combustion chamber (a bright flame; the incandescent carbon particles accelerate combustion through radiation, an effect sometimes attempted with fuel additives).

Natural gas flames, on the other hand, are low in carbon (low-luminosity flames; there are no incandescent particles to accelerate combustion), resulting in a long, diffuse flame with an indistinct end.

Do not confuse the amount of heat with the flame's capacity to transmit heat by radiation, since carbon produces less heat per kilogram than hydrogen.

This slow combustion rate in the gases can be a source of noise or vibration if the boiler's combustion chamber is insufficient in diameter.

The flame's combustion speed is determined by the velocity of the mass of gas and air being burned, especially in the cold zone or at the beginning of the flame. This can cause unstable pressures in the combustion chamber tube, resulting in noise or vibration (similar to a plumber's gas torch).

Therefore, it is necessary to create the best possible mixing of air and gaseous fuel (a mixture sometimes called turbulence) to increase the combustion rate.

Flames with a lower H/C (hydrogen/carbon) ratio (less hydrogen) produce a brighter, shorter flame with high radiant transmission, improving the efficiency percentage in the same boiler (although they are more prone to producing soot).

This is illustrated in the following table. Furthermore, the presence of hydrogen (H) influences the process, since more hydrogen increases the amount of water formed. Because efficiency in this case is represented by the Higher Heating Value (HHV), it is more affected than the Lower Heating Value (LHV).

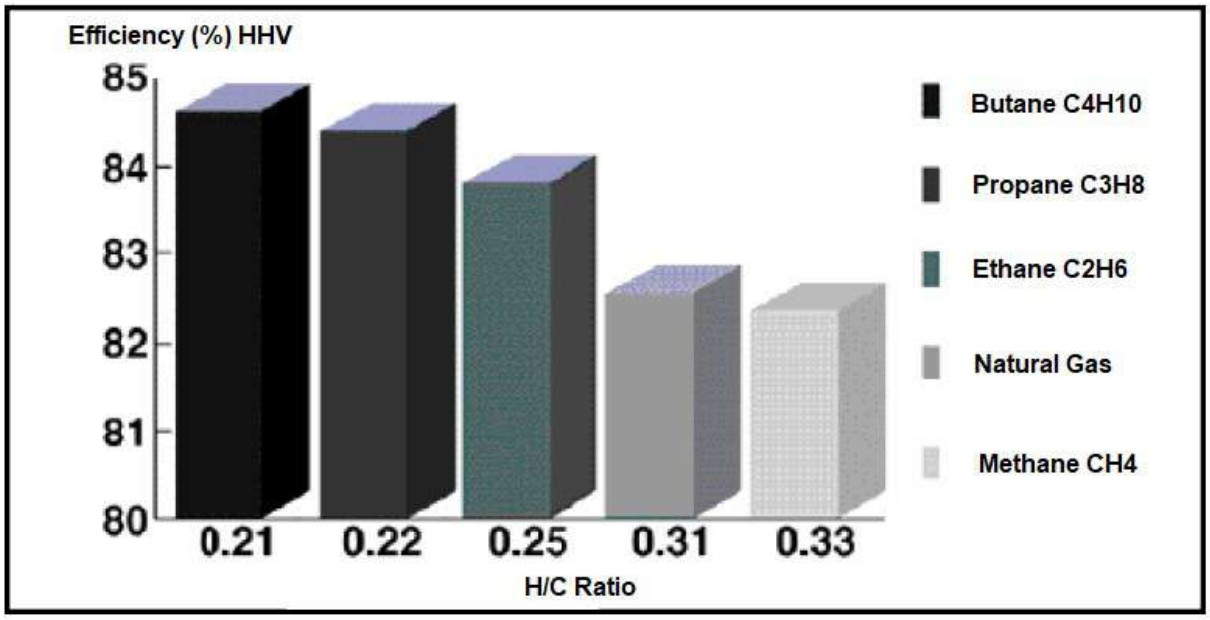
The HHV efficiency better assesses fuel behavior—specifically, the presence or formation of water—while the LHV efficiency... It better evaluates the boiler's performance.

		densidad		
		Kg/m3	P.C.S. Kcal/k	P.C.I. Kcal/kg
METANO	CH4	0.6796K/m3	13,266.46	11,955.87
ETANO	C2H6	1.2860K/m3	12,400.32	11,351.41
PROPANO	C3H8	1.9156K/m3	12,034.20	11,080.29
NBUTANO	C4H10 N	2.5339K/m3	11,838.09	10,933.62
ISOBUTANO	C4H10 I	2.5339K/m3	11,809.75	10,905.28
PENTANO ISO	C5H12 N	3.0496K/m3	11,717.53	10,843.06
PENTANO N	C5H12 I	3.0496K/m3	11,695.86	10,821.39
N HEXANO	C6H14	3.6423K/m3	11,633.64	10,779.72
ANHI.CARBON	CO2	1.8740K/m3	0.00	0.00
NITROGENO	N2	1.1915K/m3	0.00	0.00

The lower the density of a gas (the more volume it occupies per kilogram), the greater its calorific value per kilogram and the lower its calorific value per volume.

The presence of hydrogen (H), a very light element (atomic weight 1), when combined with oxygen (forming H_2O, or water), produces the greatest amount of heat per kilogram, but it occupies a large volume in its gaseous state (it is a gas that was used to inflate balloons and zeppelins, but is very dangerous due to its explosiveness; it is used in high-temperature torches, such as those used for underwater cutting, etc.).

Observe the table below which compares the different gases in their H/C ratio with respect to Combustion and Transfer Efficiency referred to the HHV (Higher Heating Value), not only due to the amount of combustion water they form, but also because the luminosity of the flame that contains more carbon transmits radiant heat better in the home.



It is clear that the **average user will receive the gas at a low pressure and with the "presence by odor" indicator already included**, but in any case, **to use said gas there will be a final reduction station, before the burner** (it will depend on the type of user).

This **final pressure reduction station** must comply with established standards, which generally require that the reduction be done in such a way as to **provide a constant pressure output**, since any variation in pressure could affect its final use (such as combustion regulation in the burner), as well as **overpressure protection** or in case of **supply interruption**.

It is clear that if there are **overpressure relief or vent valves between intermediate stages, these "leaks" must be discharged in areas free from the risk of accumulation inside the building** (or in some cases onto a flare with a pilot light so that the discharges burn off without affecting the environment; this depends on the importance of the installation).

Similarly, **the burners must have protection that, in the event of a drop in gas pressure, shuts them off and prevents them from reigniting until the supply pressure is properly restored** (gas pressure switch).

The gas must be free of foreign matter and have a very low water content. Furthermore, pressure reducing or controlling valves must be protected with filters and water traps.

Also, **when valves have diaphragms or packings that could leak gas into the atmosphere, these leaks are generally collected in a safe venting system that discharges into an open area**, away from where it could accidentally accumulate, or into a free nozzle where it can be safely burned (therefore, a pilot light must be present to initiate combustion in the event of leaks).

The calorific values of gases are expressed in relation to volumes. When this is the case, we must consider the pressure and temperature to which they refer, since the weight per cubic meter of the components will vary depending on the pressure and temperature.
Expressions of gas volumes are only meaningful when the pressure and temperature at which the volume is expressed are specified.

In the case of natural gas, volumes are sometimes expressed as Nm^3 (normal cubic meter), which is 1 m^3 of gas at 760 mm Hg absolute pressure (760 millimeters of mercury) and a temperature of 0°C (32°F).

A practical unit is the nm^3 (standard technical cubic meter), which considers the gas to be at an absolute pressure of 760 mm Hg. of Hg but at a temperature of 19.2°C (66.5°F) or 1 kg/cm^2 absolute pressure and 10°C (50°F) temperature,

this simplifies some calculations when working with the molar value—the volume occupied in m^3 by the molecular weight in kg of the gas—since the decimals are removed from the Nm^3 equivalence to the molar value. In the case of Nm^3, the value of 1 mol is taken as 22.414 m^3, and in the case of nm^3, it is taken as 24 m^3, this being a whole number that facilitates the calculations.

But a commonly used measure refers to standard conditions, such as the gas being at 15°C (59°F in the U.S.A., actually 60°F, which corresponds to 15.5°C) and 1 standard atmosphere.

(1 standard atm = 760 mm of mercury = 1.033 kg/cm^2 = 1013.25 mb or millibar = 101.325 kPa or kilopascal or 14.7 lb/in^2 or pounds per square inch).

In Uruguay, Decree 78/999 of March 22, 1999, established that the cubic meter (m³) of natural gas must be measured at a temperature of 15°C and a pressure of 101.325 kilopascals (similar to the Argentine standard).

This condition must be taken into account, since the cubic meters (m³) measured for billing purposes for natural gas consumption are based on these temperature and pressure conditions.

However, gas meters must be corrected, as they will be measuring the gas at the pressure of the pressure regulator and ambient temperature (temperature, whose variation is disregarded in low consumption; in high consumption, the meters may have an electronic pressure and temperature corrector that gives the corrected m³ of gas to standard m³).

To this must be added the factor of the ratio of the calorific values, actual GHV and agreed GHV, which is also influenced by its calorific value (which can vary). **This correction factor or "conversion factor" will be multiplied by the m³ difference indicated by the meter during the period.**

This "conversion factor" must also consider the calorific value of the gas (that is, a calorific value per standard cubic meter of gas is agreed upon, which, for example, for the natural gas supplied in Paysandú, Uruguay, is 9,300 kcal/m³ HGS in the year 2000).

We must pay attention to the "conversion factor," since if the pressure regulator changes its setting, the conversion factor must also change (in liquid fuels, consumption can be controlled by volumetric or weight measurements, which is not the case with gas; different methods must be applied, or indirect monitoring of gas usage must be maintained).

Let's take an example: the supplied gas has a gauge reading of 800 mbar (0.8 bar) and the gas's GCV (Gross Value of Gas) is 9,336 kcal/m³. The agreed-upon GCV is 9,300 kcal/m³. The meter's conversion factor will be (calculated using kg/cm²):

Conversion factor = [(1.0333 + 1.020 x 0.800) / 1.0333] x (9,336 / 9,300) = 1.796

Or, calculating in bar: [(1.013 + 0.8) / 1.013] x (9,336 / 9,300) = 1.796

The conversion factor is a ratio and is not given in any unit.

The cubic meters (m^3) read on the gas meter must be multiplied by this factor to determine the cubic meters of gas to be paid for:

(m^3 metered) x 1.796 = m^3 to be paid for (on the bill)

The first part ((1.0333 + 1.020 x 0.800) / 1.0333) corrects the volume variation per m^3 at the meter pressure to the standard pressure. The second part (9.336 / 9.300) corrects the calories supplied to the agreed-upon calories per m^3 of standard pressure.
The product of the two gives the conversion factor.

It does not correct for temperature variations (for this, meters with automatic conversion are used).

This highlights the importance of the meter operating at the specified pressure (by observing the pressure gauge and maintaining its periodic calibration), because **if the pressure on the meter drops, it will measure more m^3 than expected (this also occurs with temperature**; if it rises above normal, it will measure more m^3 than the actual volume.

In this case, it will only be useful if the compensation caused by the average between low and high temperatures is close to the standard, or if it has an automatic electronic corrector to adjust the measured m^3).

As we said, the higher calorific value (HCV) of a gas can be stated for example: 9,245 Kcal/m3 (standard cubic meter: 15ºC and 760 mm. Hg absolute), but it can also be expressed in MJ (mega-Joules, where 1MJ= 238.9 Kcal.).

Or, it could be said that the higher heating value (HHV) of this same gas is 12,709 kcal/kg (not dependent on pressure, but rather on the temperature, which is assumed to be at a certain value, generally 0°C 32°F).

We can also define that for this gas (this particular one), a minimum volume of air is needed for its complete combustion, saying, for example, that 1 m^3 of this gas requires 9.8 m^3 of air for its complete combustion.

However, since gases have many variations in composition, a calculation has been defined to determine if one gas can substitute for another in the same burner and at the same gas pressure.

This calculation uses an index called the Woobe Index, defined as the ratio between the Higher Heating Value (HHV) and the square root of the

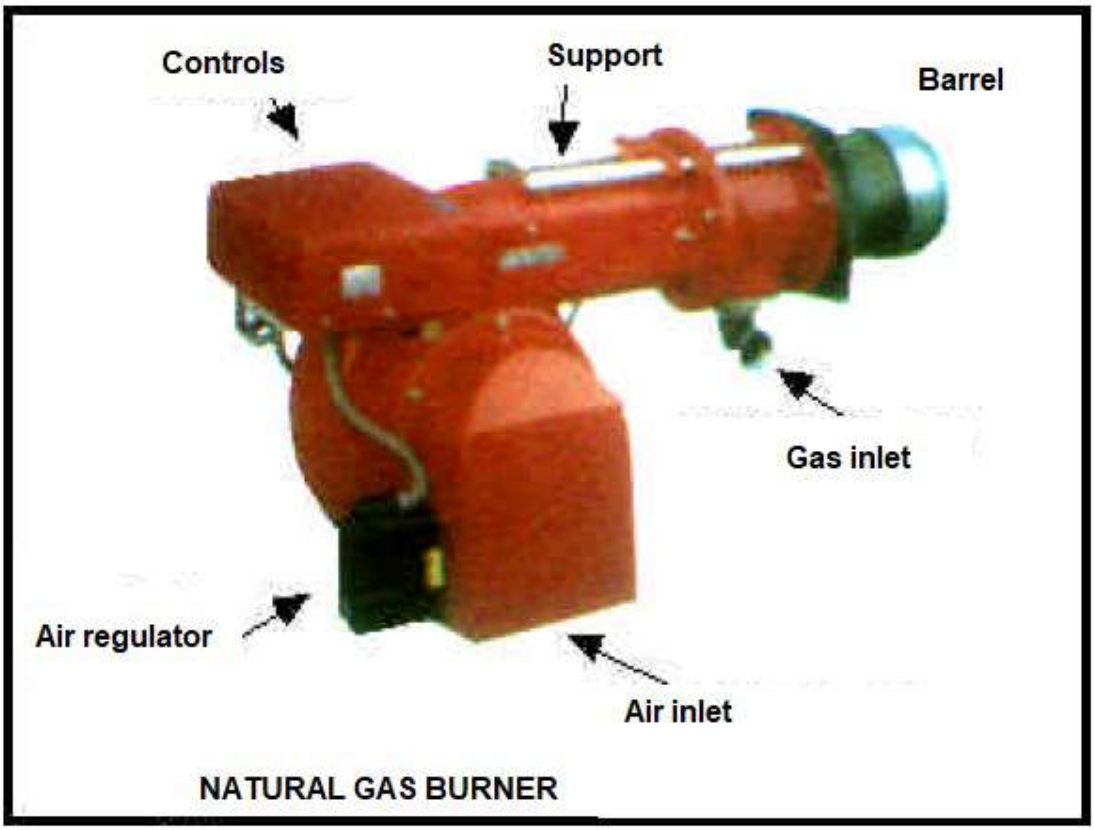
relative density (using the HHV in MJ/m³ and the relative density relative to air, where air = 1).

For example, if the gas has a HHV of 40.1 MJ/m³ and a relative density of 0.64, the Woobe Index will be 50.1.

At similar or close Woobe indices, these fuels can be interchanged in the same burner without needing to change the gas injection nozzles; otherwise, changes will have to be made to the burner each time different gases are used.

For example: General specification for piped natural gas:

Higher Heating Value..... 36.51 to 41.0 MJ/m³
Wobbe Index ..... 46.02 to 50.86
Water..... 112 kg/m³
Hydrocarbon dew point.....max.. 2.2°C at 7 MPa (relative)
Oxygen.....max. 0.2% vol.
Total Sulfur.....max... 45.74 mg/m³
Hydrogen Sulfide.....max... 6.0 mg/m³
Sulfur Mercaptan.....max... 4.57 mg/m³



2- The burner must meet all the necessary requirements for burning natural gas:

Handling natural gas “seems easy,” but if we want to avoid accidents, we must ensure **that the burner complies with all safety standards** (in Uruguay, Argentine standards have been adopted, but also European ones, since burners from all over the world are used). This includes ensuring the programmer is suitable for gas (generally, there is more consideration given to the purging process—4 air changes per minute in the combustion chamber volume—than in a liquid fuel burner).

If reignition occurs, the purging process must be repeated each time (in large boilers, there will be no re-ignition, only post-purge, and the boiler operator must perform the “reset” or “reset” of the burner, which will be “locked out” due to ignition failure, so that the boiler operator can investigate the fault).

In "small" boilers there may only be a "spark" for direct ignition of the main flame, but in larger boilers there must be a gas pilot flame that is ignited by the "spark," and in some cases, the pilot flame may always be lit to prevent the presence of unburned gas.

But in automatic burners, the pilot flame will be interruptible, meaning it will operate for a few seconds with the electric igniter to ignite the pilot flame, then for a few seconds to establish the pilot flame on its own so that the flame control photocell (special for gas) "sees" it.

The pilot will remain lit for a few seconds to ignite the main flame (about 3 to 5 seconds more for the main flame to establish itself, depending on the burner's capacity), which must shut off in 1 second if the pilot goes out and/or the main flame does not establish itself.

In other cases, there may be an intermittent pilot light, meaning it remains lit as long as the main flame is lit.
Each case will depend on the importance of the burner and the type of boiler (according to the regulations and/or the boiler manufacturer).

The "power" or flow rate of the main flame at ignition must be a fraction of the maximum flow rate (or maximum burner power). As the boiler's capacity increases, this fraction decreases (reaching 20% in the largest boilers).

Only in small-capacity boilers (less than 100,000 kcal/h) can the main flame be ignited at full flow rate. **However, all the "safety" enabling valves in the valve train that supply gas to the burner must open slowly (to prevent an ignition explosion) and close rapidly (in less than 1 second in larger boilers).**

Flame control can be achieved using an ionization rod to monitor the flame, and/or a combustion (flame) detector that uses ultraviolet light instead of visible light or infrared, or both.

It is very important to comply with the regulations established by the authorities in each region or country.

The ionization rod is based on the principle that gas combustion ionizes gas particles, creating particles with positive and negative charges (which allows us to pass a certain electrical current between two elements subjected to a certain voltage; dry air does not conduct electricity).

Using this property, the rod or electrode is at a voltage relative to "ground," that is, the metallic "mass" of the burner or another electrode.

If combustion occurs, current flows, activating a circuit to detect the flame. If there is no combustion, the current is not established, and the circuit does not detect it.

The electromagnetic spectrum that makes up light has frequencies (like radio waves or television) at which some are visible—visible light, which is made up of the primary colors.

But at lower frequencies, we enter the infrared spectrum (those we detect by the heat they transmit). At the other end of the light spectrum are ultraviolet light waves (which are almost invisible).

The combustion of natural gas produces more ultraviolet waves (almost invisible or invisible).

In common burners, the common photoelectric cells or silicon or germanium photo-iodes are generally not suitable for gas, because gas transmits few visible or infrared waves. **Therefore, if there is a conversion of a liquid fuel burner to burn gas, this is one of the points to consider, since it may be a cell exclusively for liquid fuel, which generally detect more visible or infrared waves.**

UV (ultraviolet) sensors have generally been the most commonly used for gas detection (photodiodes with filters or ionization rods can also be used).

Ionization rods can be used in conjunction with UV sensors. **The response time for detecting a flame failure is a maximum of 3-5 seconds** (though some modern photocells are less than 1 second) when the pilot light attempts to ignite, and then the main flame fails.

The pilot light is ignited by the igniter, which is set beforehand in about 3 seconds (it is not detected by the flame detector). **The gas pilot should ignite within 3 to 5 seconds, and the igniter should be turned off to see if the pilot flame stabilizes (this should be observed by the flame detector).**

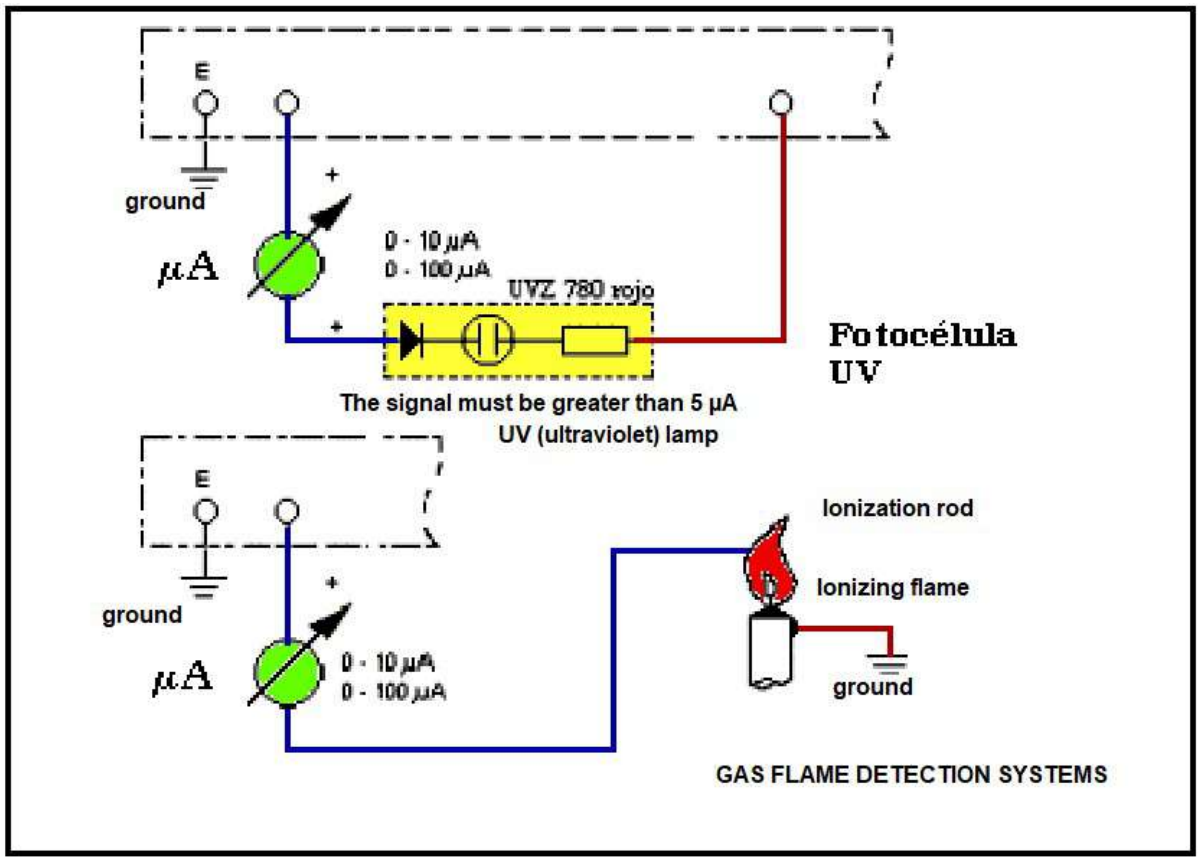
If the gas pilot does not stabilize, the gas supply to the burner will be cut off in less than 1 second, and the burner will be locked out with the fault light and alarm activated until the operator inspects and restarts the burner (resetting it).

In other words, the response of the flame detector is generally less than 1 second and the quick-closing valves are practically instantaneous (less than 1 second), this depends on the "power" of the boiler (capacity, see table below).

The main flame ignites within 3 to 5 seconds, depending on the burner type and power, in the minimum flame setting (20% of maximum capacity in larger boilers), if the main flame does not ignite within this time, the burner "locks out" due to lack of flame (since it only has 3 to 5 seconds to ignite).

This triggers a post-sweep and indicates the lock position by illuminating the "lock" light and sounding an alarm (with the fault indicated on a display or the time it occurred on a rotary dial).

Some photocells, which operate in the infrared range, run the risk of detecting the heat from refractory materials, which can cause them to fail to shut off due to lack of flame. For this reason, photocells must be selected by a trained technician and in accordance with the standards.



UV-type photocells, with the appropriate circuitry, can work by detecting, in the case of some flames, a "frequency or alternation" produced by combustion, so that there is no way to mistake the presence of a flame for the heat produced by refractories that do not produce said "frequency".

In turn, some of these circuits have permanent intrinsic checks to determine if the photocell tends to "wear out" or another problem that could cause a false reading of the presence or absence of a flame.

UV flame sensors and "ionization rods" work, in a way, on the same principle: the ionization of a gas between two plates or conductive elements (the ionized gas means that its molecules are positively and negatively charged, allowing a small electric current to flow when subjected to a voltage between these "plates" or conductive parts).

UV photocells are actually a "glass tube" like a light bulb (they're like the ones we used in old vacuum tube radios and called "diodes" because they have two electrodes), sealed with plates, one called the "cathode" and the other the "anode."

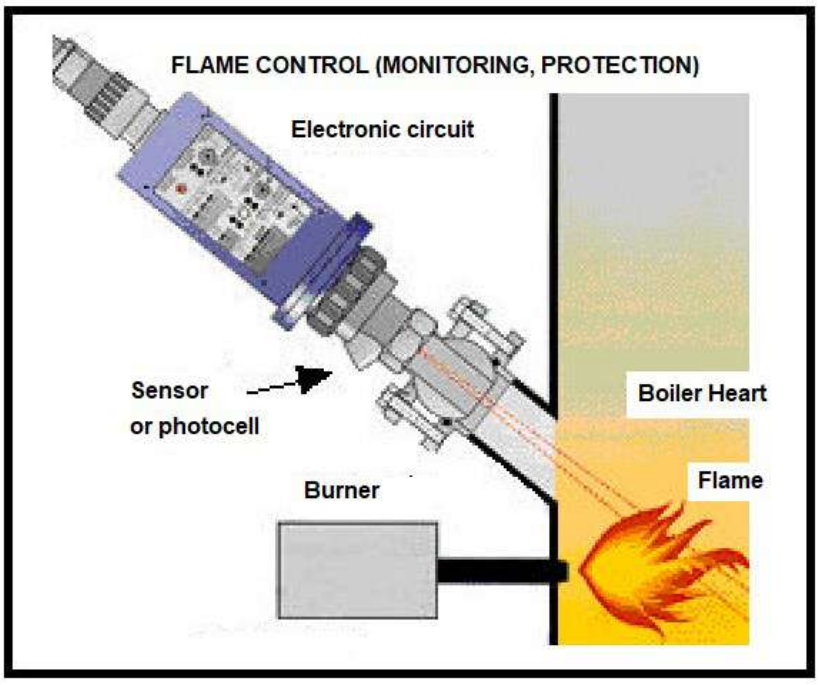
Inside the tube, instead of air or a vacuum, there's a gas that ionizes when illuminated by ultraviolet light. This allows it to conduct a small electrical current, which is used to operate a relay that controls the burner's electrical circuit.

The ionization rods are actually similar to the electrodes of the burner's spark system, since a single electrode is given voltage with respect to the "ground" formed by the metal burner, and air by itself does not ionize, but when there is a flame (combustion gas) it ionizes and allows the passage of a small electrical current that is used to operate a relay that controls the burner circuit.

According to the standards, two flame control systems can be installed in parallel (American standards allow this so that one can be removed for maintenance without having to shut down the burner).

However, Argentine standards only allow two flame control systems, meaning that each flame control operates independently of the other. Therefore, if either one fails, the burner will shut down.

When the burner output is of a certain importance (more than 5,000,000 Kcal/h) the flame control sensors must be "self-testing" (with "intrinsic safety", i.e., able to test themselves and block the burner if there is a failure in the system) especially if the boiler is running continuously.



A burner of a certain power output must have a combustion **air supply pressure sensor** to ensure that combustion air is present when the burner ignites or operates (because if gas enters and there is no "purge" or combustion air, and the igniter ignites, a combustion explosion is almost certain).

The "electrical interlock" of the burner fan is not sufficient (as the fan itself could break the connection between the motor and the fan's impeller).

When there are multiple burners on the same boiler, each burner must have its own independent pressure and flame sensor.

To all these elements must be added the "train" or set of safety valves (with their "leakage" test elements, i.e., gas loss from the valves) and control, with their pressure switches, "position" sensors, regulating valves, etc., as we will describe later.

3- The boiler room must be adequate:

It is clear that the boiler room must have good ventilation, meaning there must be constant air exchange to prevent gas from accumulating in the room, as this can lead to violent combustion (lean mixtures produce more violent explosions than rich mixtures).

Remember that natural gas is a mixture of gases, some light like methane (CH4, almost 95%), others heavier like ethane (C2H6) and propane (C3H8).

This means that some of the lost gas will rise (most of it) and some will sink.

In a gas conversión (fuel to natural gas burners), especially in buildings, heating boilers often suffer from a significant lack of ventilation.

This ventilation must allow for the extraction of stale air or suspected gas leaks into the atmosphere, not into other areas where they could accumulate.

Remember that when installing exhaust fans, we must also ensure there are adequate air intakes; otherwise, proper air exchange will not be possible.

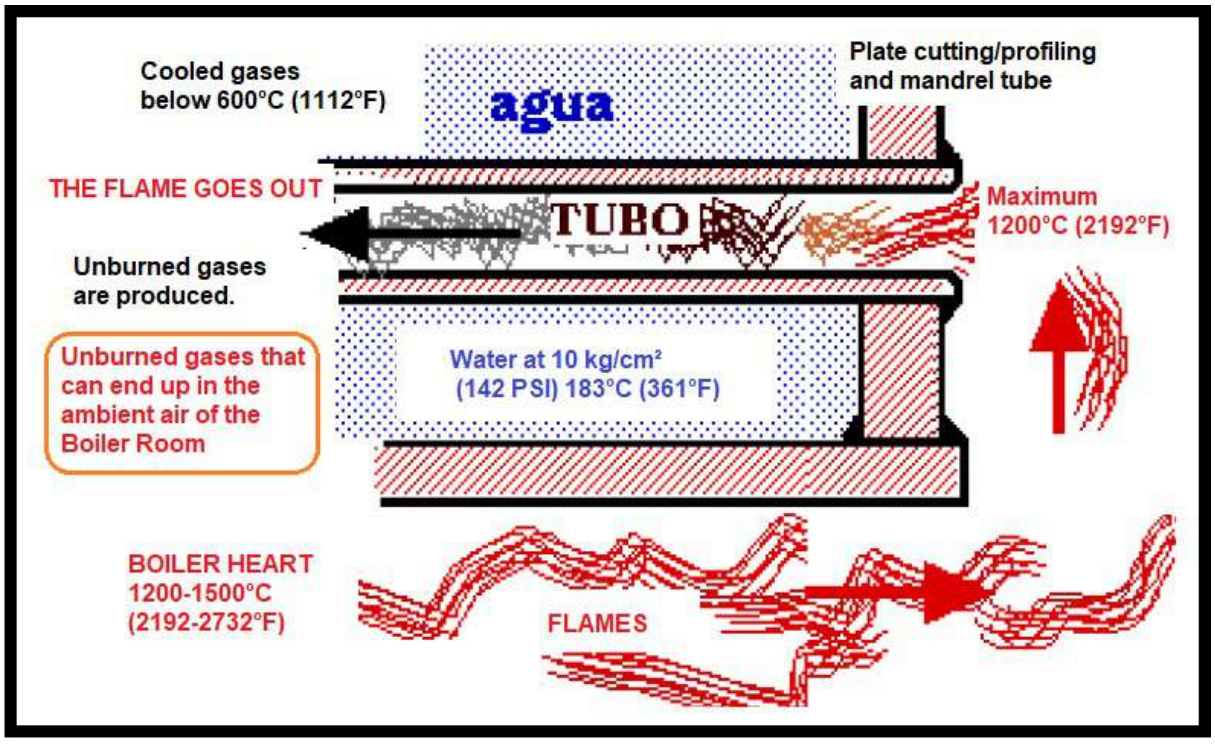
The combustion chambers of older boilers were generally under negative pressure, meaning that the chimney created a draft or suction in the boiler's combustion chamber when the boiler was running (a few millimeters of water column, depending on the chimney's height and diameter, flue gas temperature, and boiler type).

Modern natural gas boilers tend to have a pressurized combustion chamber when they are running (the gases are forced through the tubes and their retarders, if used), and negative pressure will only be present in the combustion chamber when the boiler's combustion chamber is off (and the burner's air intake is closed).

This means that in pressurized combustion chamber boilers, combustion gas leaks can enter the room. In other words, in natural gas boilers where the burners pressurize the combustion chamber, gas can escape into the room through poorly sealed combustion chamber lids or smoke boxes.

Boilers with a slightly negative pressure in the combustion chamber are less likely to experience combustion gas leaks into the room.

It's important to remember that once combustion extends beyond the flue pipes, the flame goes out and unburned gases are generated.



These unburned gases can be released into the environment as unburned gases, especially in the flue or chimney connection.

This can also happen when chimneys are clogged by corrosion, old soot, or debris, or when they are poorly designed or constructed. (Sometimes an internal chimney fire causes the flue to contract, which isn't visible from the outside, creating a partial obstruction that prevents proper chimney draft.)

These gases, produced by incomplete combustion, can not only be explosive but are also highly toxic, especially due to the presence of carbon monoxide (CO).

Remember that carbon monoxide (CO) is a gas whose effect on the human body is cumulative with prolonged exposure to contaminated air. This means that prolonged exposure increases the risk of poisoning, even with low levels of carbon monoxide (CO).

Carbon monoxide (CO) is a colorless and odorless gas.

Generally, before it can have a fatal effect, it causes headaches and nausea, and before that, there are some other barely noticeable symptoms. For example:

According to the Bureau of Standards (paper 212), 8% CO exposure can be fatal for 1.5 hours, but 4% CO exposure can also be fatal for slightly over 4 hours.

However, if a person remains in a contaminated environment for extended periods, even with a lower percentage of CO, death may occur, but other complications will arise that will affect their health for life, even if they don't die immediately. This is because they may experience periods of fresh air alternating with exposure to CO-contaminated air.

The maximum CO content that natural gas can reach is approximately 15%, a situation that would require either a 25% air deficiency (to reach the minimum air quantity) or a very poor air-gas mixture.

However, having 1% to 2% CO in flue gases is not unrealistic. Therefore, natural gas burners should be monitored periodically with instruments to check for the undesirable presence of CO and correct the situation, since visual inspection is not possible because there are no visible smokes or the flame color is not precise).

This means that, primarily for this reason and for economic reasons (energy loss), **the maximum acceptable CO level in natural gas combustion chimneys is generally 400 ppm** (parts per million, equivalent to approximately 0.04% CO) in the flue gases.

However, in a "good" and "properly adjusted" burner, the CO level should be practically "nonexistent."

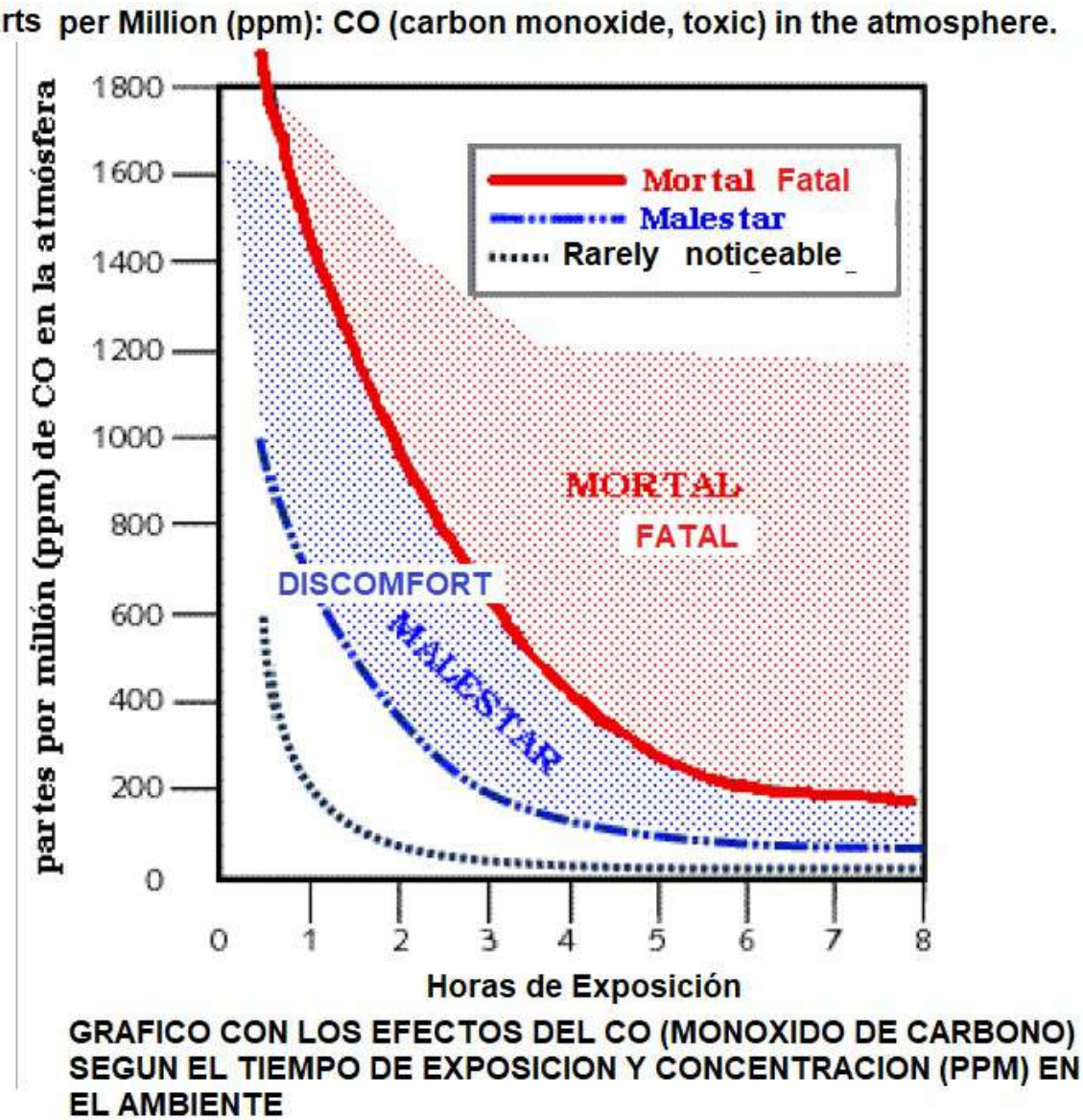


GRAFICO CON LOS EFECTOS DEL CO (MONOXIDO DE CARBONO) SEGUN EL TIEMPO DE EXPOSICION Y CONCENTRACION (PPM) EN EL AMBIENTE

GRAFICO CON LOS EFECTOS DEL CO (MONOXIDO DE CARBONO) SEGUN EL TIEMPO DE EXPOSICION Y CONCENTRACION (PPM) EN EL AMBIENTE

The composition of the chimney flue gases, assuming no CO (carbon monoxide) and the minimum amount of air used (without excess, which is theoretical; in practice, an excess of air will always be used, though it should be kept to a minimum), will be approximately the following percentages by volume:

Composition of chimney gases (Natural Gas)

Component	**on a wet basis**	**on a dry basis**
CO2.....	9.90%	12.20%
H2O.....	18.5%	0.00%
N2.....	71.6%	87.80%

See here the importance of the water (H2O) formed, due to the large amount of hydrogen (H2) in the natural gas.

At the time of "start-up" with the cold boiler a large amount of water is produced by condensation, which condenses in the boiler's furnace, which then evaporates, **but which is the cause of possible corrosion if this operation occurs day after day**).

In the event of a gas leak (detected by smell): do not turn on any electrical appliances, move people away from the area, and call the gas company (or fire department) as they have the appropriate equipment and knowledge (as well as training).

See the end of this section for some considerations regarding the supply of natural gas to burners.

Never attempt to detect a gas leak with a lighter, candle, or match. If it is necessary to check for a leak at the burner (i.e., the user's area), use soapy water (look for bubbles)!

We will see next point 4- The burner must be adjusted using instruments.

CHAPTER 5: Operation Part 7 Natural Gas Burners [4 of 5]

4- The burner must be adjusted using instruments.

Natural gas combustion is not luminous, with a visible flame. Only the central part of the flame will be visible, appearing as a diffuse color, making it impossible to see where the combustion ends (the flame length).

The lack or excess of air is not easily observed by the color or shape of the flame. In reality, two combustion conditions occur: one with a dim, bluish glow (since the carbon and hydrogen ignite almost directly with the air mixture due to perfect mixing, an effect called hydroxylation),

And another, brighter, with a lighter, yellowish color, due to the decomposition of the gas upon entering a high-temperature zone, without having achieved perfect mixing with the air. This causes the gas to decompose into its hydrogen and carbon components or into other carbon and hydrogen components (an effect called cracking).

It is the carbon particles that produce the incandescent glow, combusting upon encountering oxygen or otherwise forming a deposit or soot particle if they come into contact with a cold surface (similar to liquid fuels).

This soot formation can be noticed as the chimney temperature rises. However, incomplete combustion can occur, not visible at the end of the flame. This can lead to the formation of imperceptible soot in the chimney flue gases (but when the accumulation is significant, its expulsion through the chimney becomes noticeable in patios and roofs).

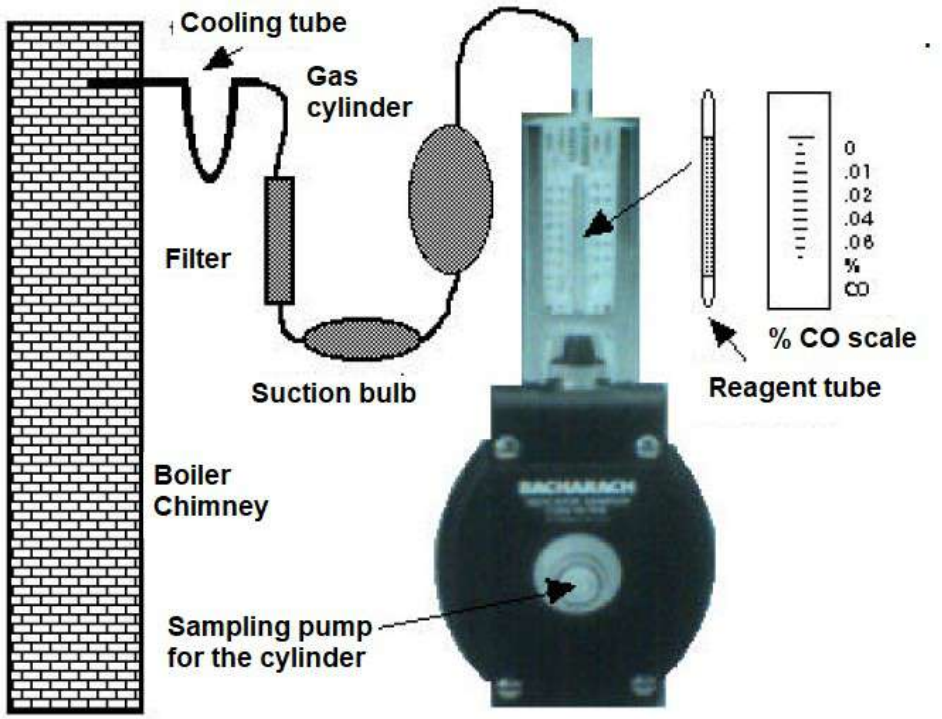
Generally, the combustion of natural gas does not produce "visible smoke" as in the burning of liquid fuels, that is: the lack or excess of air is not easily observed through the smoke, poor combustion (unburned products, from the gas itself to carbon monoxide, hydrogen or organic elements, some such as "pyroligneous" type acids, which are corrosive, in addition to being pollutants).

This means that when adjusting the excess air in a gas burner, it's generally necessary to use instruments that measure CO2 (carbon dioxide) or O2 (oxygen) in the flue gases.

It's also advisable to measure unburned gases or CO (carbon monoxide),

which should be at the minimum permissible level according to local regulations (generally less than 400 ppm of CO, or 0.04% CO). Otherwise, we risk being in an area with insufficient air and not being able to detect it visually.

INDICADOR DE MONOXIDO (MONOXOR BACHARACH)



As we have said, measuring carbon monoxide (CO) in gas combustion is very important, both to prevent air pollution and from an economic point of view (since if CO is present, it can be considered that there are twice as many losses from other "partially burned" volatiles, unless the instrument measures "unburned" gases and not just CO).

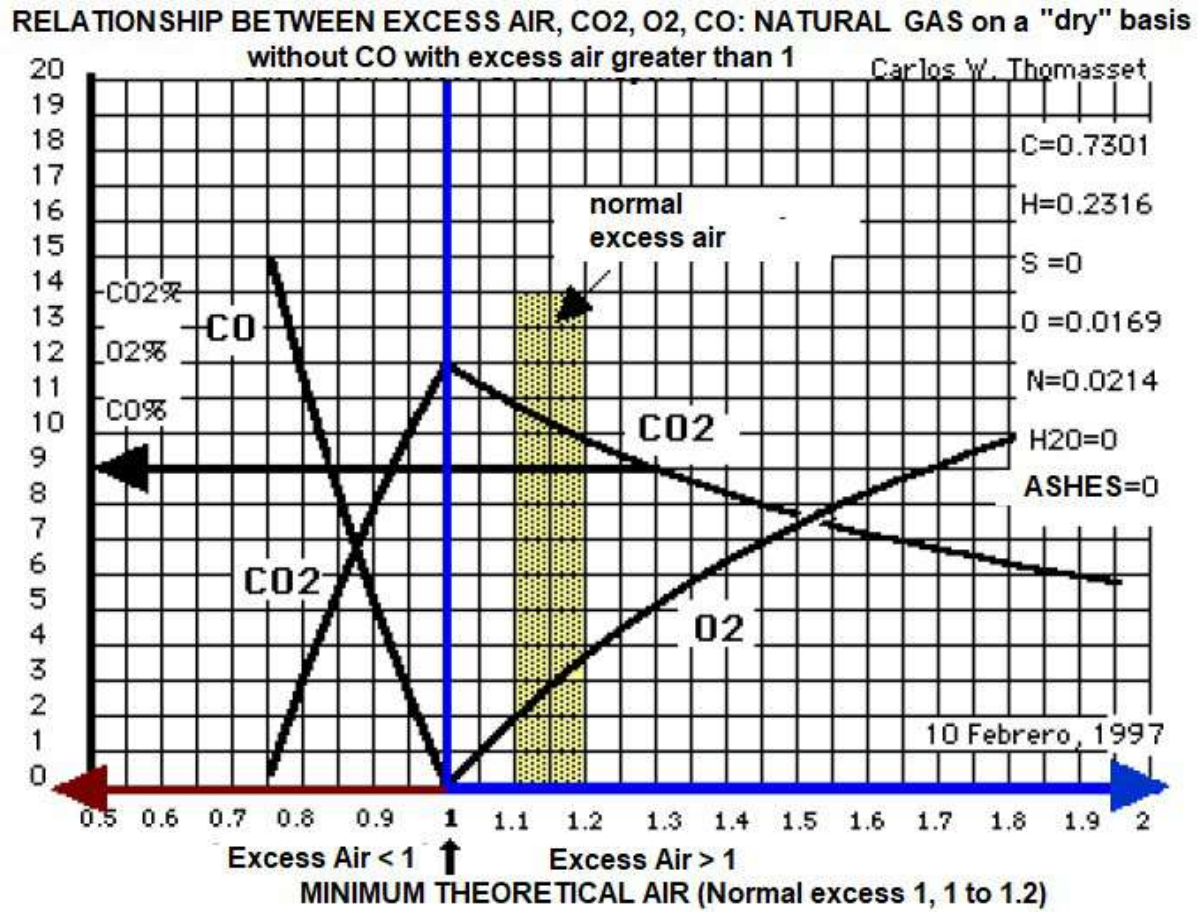
Since gas combustion does not produce smoke, it is important to take this measurement. There are several instruments to measure CO, it can be an **ORSAT** (which measures CO2, O2 and CO), it can be an electrical/electronic instrument or it can be a simple instrument like the **MONOXOR® from BACHARACH™** (its manufacture is discontinued [year 2001], but these devices are still in use).

The MONOXOR® for measuring CO is based on passing a measured amount of flue gas, which is previously stored in a rubber balloon (which is filled with flue gas through a cooler and a filter, propelled with a rubber bulb that acts as a pump). This gas from the cylinder, measured by a volume-

calibrated pump, is passed through a small tube filled with a yellow, sandy substance. When a certain amount of gas is drawn in by a pump from the Monoxor® itself, if the gas contains CO, the yellow color changes to a dark color.

The longer the color change in the tube will be, the greater the percentage of CO_2. A scale will indicate the percentage of CO_2 (after one use, if the tube hasn't darkened more than halfway, it can be inverted and used again). Its manufacture has been discontinued by BACHARACH™.

Generally, when burning gas, the CO content should not exceed 0.04% (400 ppm). See the following graph. While the maximum CO2 values in gases are lower than those in liquid fuels (due to a higher hydrogen-to-carbon ratio), if we only measure CO2 or O2, **we risk being in an area of poor air quality and having a quantity of unburned gases that are not visible due to the flame color or the smoke in the chimney.** This is not only polluting, it's also a potentially significant economic loss; furthermore, these flue gases can be highly corrosive. See this theoretical combustion diagram:



This means that for the same CO2 measurement, we can be in an area of excess air or lack of air.

However, if we also measure oxygen and there is an excess, it doesn't necessarily mean that this corresponds to an actual excess of air, since there could be excess oxygen due to "incomplete combustion" (whether due to a poor mixture of air and gas, excessive flame cooling, or insufficient combustion time in the combustion chamber).

This situation doesn't appear in this diagram, but it does appear in the Ostwald triangle, which I recommend using to study combustion problems.

To calculate excess air, a mathematical formula is generally used that involves CO2, O2, and CO. This way, regardless of the fuel composition, the calculation will yield the excess air.

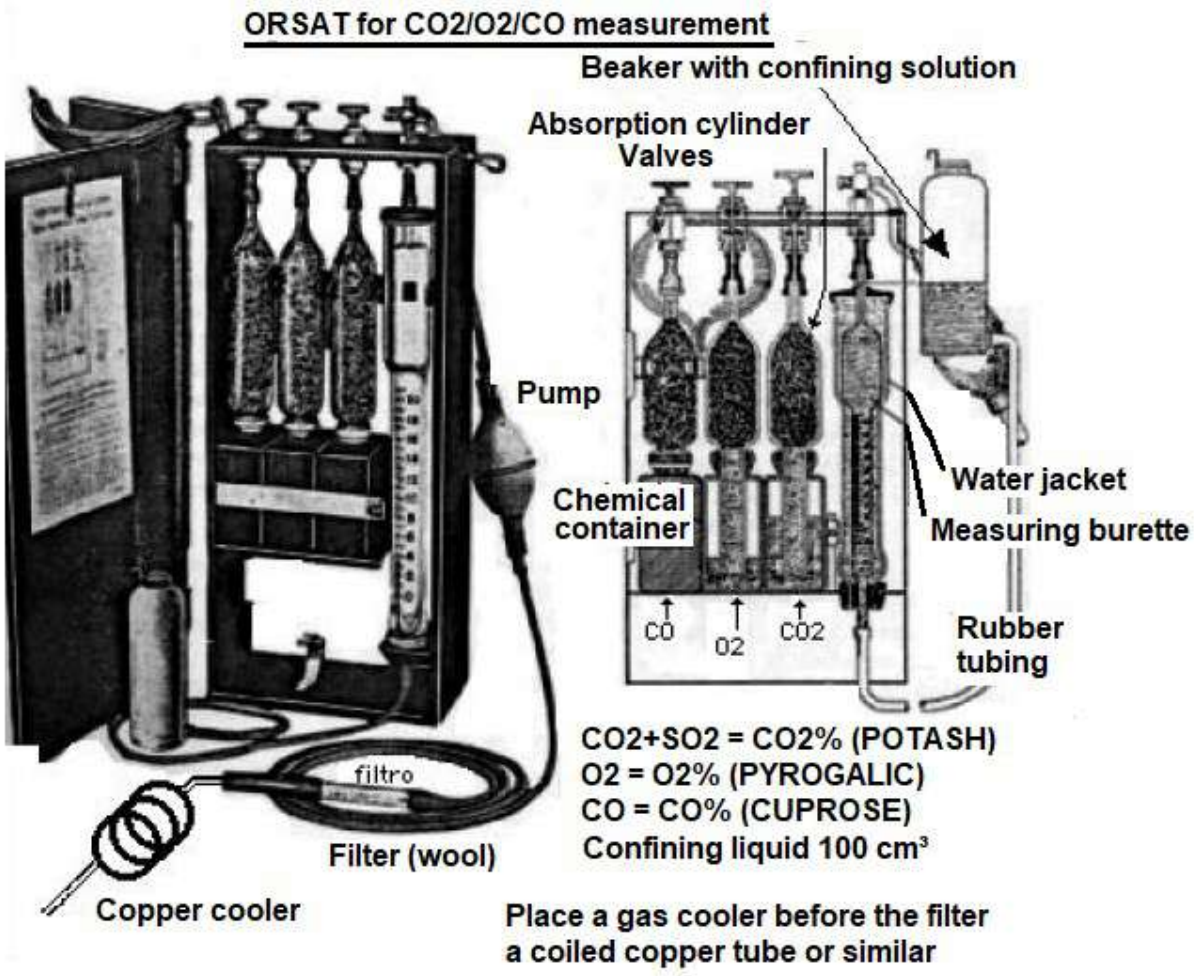
All these chemical measurement devices (Fyrite®, Mono, ORSAT, etc.) use a dry basis. The CO2 measurement also includes the presence of SO2 (sulfur dioxide), which volumetrically responds in the same ratio as CO2 to oxygen (for calculating excess air).

That is, we take it as CO2 when in reality it is a mixture of CO2 + SO2 (the incidence of SO2 is very low in the variation of the % reading of excess air when taking it into account as CO2, given the relatively low sulfur content of fuels compared to carbon).

THE ORSAT SET

The ORSAT is a very "old" device, but still useful for measuring combustion gases. While its measurement isn't highly precise, its reading is relatively reliable when **used in conjunction with an Ostwald triangle**.

Its operation is based on taking a pre-cooled sample through a wool filter, drawn in by a rubber pump (of the "barber's" type). The sample is then pushed through a 100 cm³ graduated measuring burette (which is submerged in another container filled with water to maintain a stable sample temperature).



The propelled gas is then forced out through a beaker filled with a "confinement liquid" (a liquid that does not absorb the gases and allows us to raise or lower the beaker to push or draw the gas through the different absorption liquids).

Once enough flue gas had passed through the measuring burette (as if washing with gases to ensure its original constitution), we maneuvered the inlet and exhaust valves to the atmosphere, so that with the beaker we leveled the zero (0 equivalent to 100 cm3 of sample, leveling the surface of the confining liquid in the burette and in the beaker to the same level, so as not to compress or expand the gas sample) of the burette.

Before performing this maneuver to "capture" 100 cm3 of gas, we must level all the absorption liquids in each absorption chamber (where the fillings are, glass tubes or copper chips or wires, which are soaked in the absorption liquid to be able to selectively absorb each gas; it is filled to the mark it has on the thinnest neck).

Next, we will push the gas so that it enters completely into the first absorption chamber (to absorb CO2 and SO2, carbon dioxide and sulfur dioxide, which is absorbed by a strong potassium hydroxide solution). We repeat the process of pushing and returning the gas to the measuring burette as many times as necessary to ensure a constant reading.

We must take care to return the absorbent liquid to the same mark in its container, as each absorption chamber discharges the liquid into a container sealed from the atmosphere by a balloon to prevent contact with the air. The absorbent liquid contains approximately 100 cm^3.

Then, with the constant reading, the reading of each 1 cm3 or 1 ml will be the % of CO2% (to make this reading, level the burette and the beaker, taking care that the effect of the "menisci" of the confining liquid in both are equal).

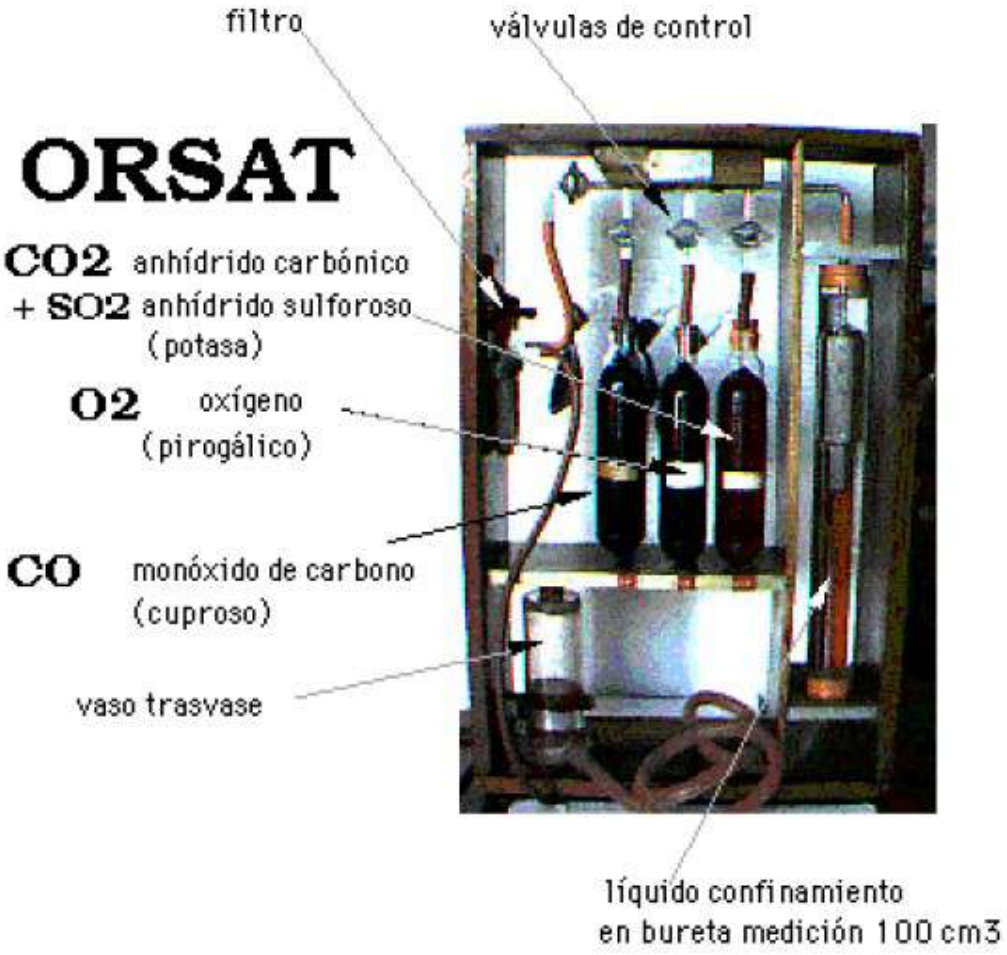
Here the remaining gas will be less than 100 cm^3 (since it loses CO_2 and SO_2, it could also lose some acid gases, but it is all taken as CO_2 given the low influence of SO_2 and acid gases on the percentage). The reading will be on a dry basis (dry gases).

Now we will absorb the O_2 (using pyrogallic acid, a wood derivative, as the absorbent. This acid must not be in contact with the atmosphere, otherwise it loses effectiveness due to the presence of atmospheric O_2).

Once the O2 is absorbed, the burette reading will be the difference between the CO2 + SO2 + O2 concentration and the previous CO2% (+SO2) reading. Next, we will absorb the CO (using a cuprous chloride solution).

The reading for this measurement will be the CO2 + SO2 + O2 + CO concentration, so the CO% will be this reading minus the previous one.

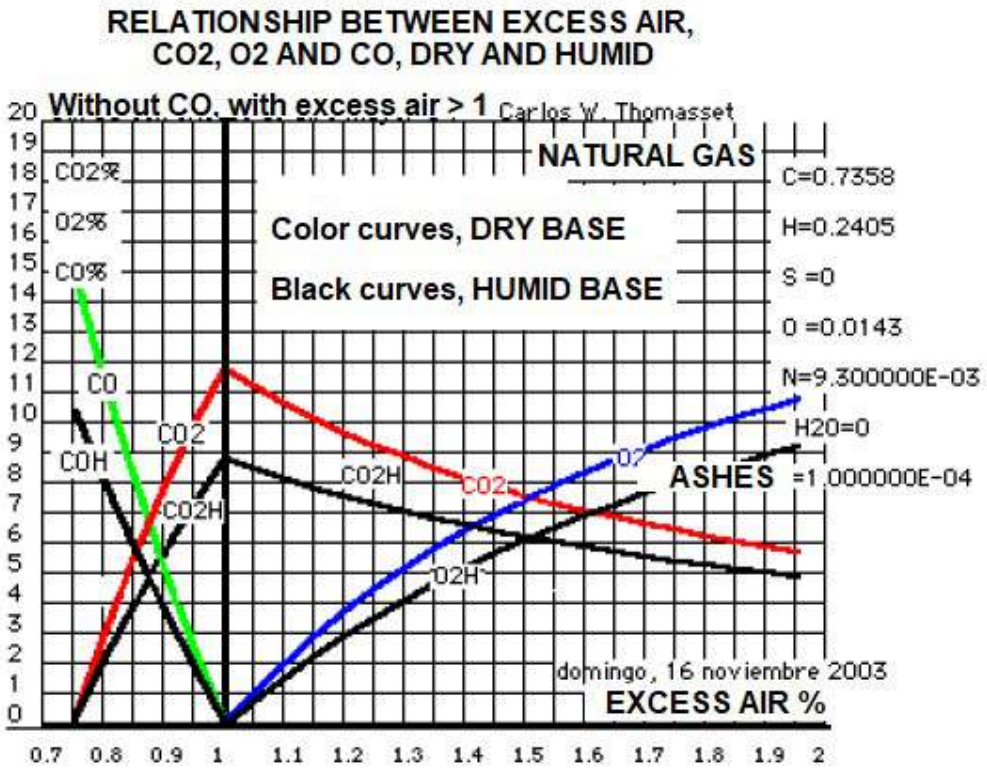
Absorption liquids should be prepared as absorption problems are observed (the maneuver must be repeated many times to absorb, since the color and viscosity give an idea that there is a change in them, especially in pyrogallic and cuprous, taking into account that cuprous is poisonous).



Then, for better use and interpretation of ORSAT, it is advisable to use an OSTWALD diagram, since although we can know the excess air by means of a formula in which the 3 measured elements (CO2%, O2% and CO%, see below a formula to calculate the excess air with incomplete combustion, in which CO2, O2, CO participate, in dry ratio) without needing to know the composition of the fuel, which is necessary to draw the OSTWALD triangle

(do not forget that the OSTWALD triangle is the ratio of the combustion gases in dry ratio, that is, with the condensed water vapor).

$$\&(ex.aire)=\frac{(1-CO2-O2-CO)}{(1-CO2-1,5\,CO-((O2-0,5\,CO)/0,21))}$$



Observe in the graph above the difference between the percentage ratio of flue gases on a "dry" basis and on a "wet" basis (CO2H, O2H, COH) for natural gas (i.e., as found in the chimney and not as found after being drawn into a device that cools and condenses all or part of the combustion water and moisture from the fuel and combustion air).

Instruments that reflect measurements on a "wet" basis are the most common: zirconium oxide cells (which operate inside the chimney at high temperatures), or other instruments that operate at high temperatures that prevent condensation.

Instruments that bring the gases to the ambient temperature of the measuring device and are not "absorption" instruments, such as the Fyrite® and the ORSAT, provide gas ratios with such a low percentage of humidity

that their value is practically on a dry basis. Furthermore, if greater accuracy is desired, a correction for temperature under the measurement conditions must be made.

THE OSTWALD TRIANGLE IN NATURAL GAS UTILIZATION

To facilitate burner adjustments, the OSTWALD triangle can be used. This triangle represents a dry-basis gas ratio (meaning that the moisture content—water from combustion and moisture from the air and gas—present in the combustion gases is assumed to be condensed).

It is a graph that relates these same values, but each curve on the graph is plotted for only one type of fuel, as it corresponds to the specific composition of each fuel.

The vertical lines represent the CO2% by volume values (CO2 + SO2), and the horizontal line represents the percentage of oxygen (with the maximum O2 for air being 21% by volume).

Starting from the maximum CO2%, that is, the point where the air used is at its "minimum" or "stoichiometric" level—neither excess nor insufficient air—which in natural gas is approximately 12% (the point where all the oxygen is consumed, i.e., 0%), a line is drawn connecting to the maximum oxygen point (21% O2 and 0% CO2, i.e., no gases or infinite excess air).

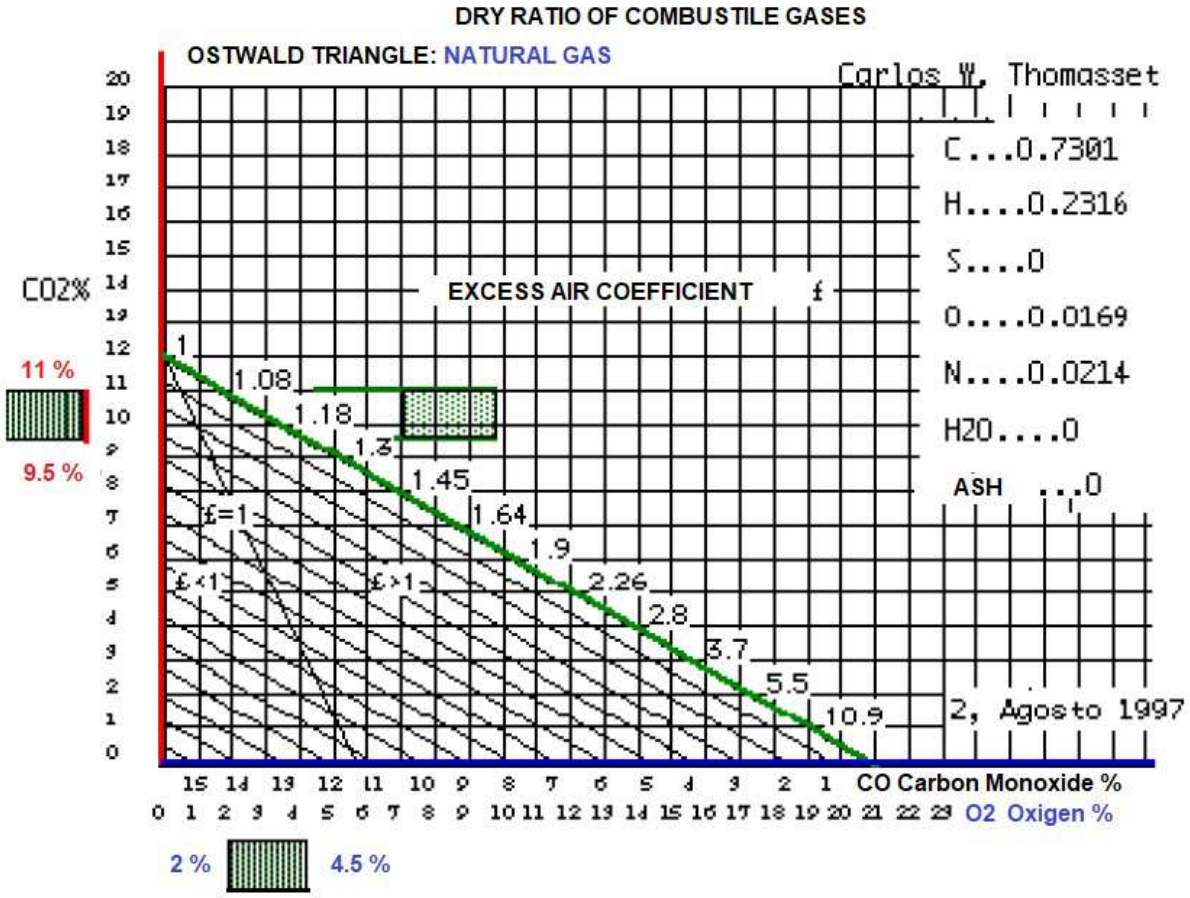
On this line will be the values for excess air with complete combustion (with CO equal to 0%). Parallel to this line will be the increasing CO% values, with the maximum CO occurring at the intersection of CO2 equal to 0% and oxygen equal to 0%, which in this case will be 15.5%.

This Ostwald triangle was drawn based on the average composition of natural gas. Accordingly, when adjusting a natural gas burner, CO2 or O2 should be measured, in addition to unburned gases or CO (carbon monoxide). For this, we can use independent meters or an ORSAT.

The ORSAT measures CO2 (plus SO2), O2, and CO by chemical absorption. Based on these three measurements, we can use the Ostwald triangle to understand what is happening with the burner or mathematically calculate the excess air.

The ORSAT is an instrument that has been widely used for many years, and while it is not highly precise, it is very useful, and in a country like ours, its use is still very convenient. (Modern electronic equipment, much of it

computerized, requires periodic and costly calibrations, detector replacements, and firmware, software, and operating system updates, which makes them impractical.)



THE OSTWALD TRIANGLE IN MORE DETAIL

This chart, a visual system for viewing the combustion results, is plotted as a percentage of dry gas volume and is used as follows:

It is a triangle formed by the vertical leg (ordinate) representing the CO2% of each particular fuel (each triangle is only valid for each fuel, since its shape corresponds to the chemical composition of the fuel and the Earth's atmosphere at sea level, and with dry gases), in which the CO2% corresponds to the sum of CO2% + SO2% (since both elements require the same volume or molarity of oxygen, and since the absorption instruments will absorb both, and the incidence of SO2%, sulfur dioxide, is generally low), meaning that the maximum value will be the maximum CO2% of the fuel (the sum of CO2% + SO2%, when the air required corresponds to the minimum or stoichiometric amount, with complete combustion).

This maximum CO2% will be higher as the hydrogen/carbon ratio decreases (H/C), meaning the fuel has more carbon in relation to hydrogen (we can order fuels from highest to lowest hydrogen content: generally natural gases, light liquid fuels contain more hydrogen, and heavy liquid fuels, such as fuel oil, and generally solid fuels such as firewood, lignite, and coal in general, have higher carbon content).

On the horizontal leg (abscissa), the percentage of O2 (atmospheric oxygen, approximately 21% by volume) is plotted up to 21%.

The hypotenuse will be the point of intersection of complete combustion, where the values corresponding to each specific CO2% and O2% value intersect. This indicates the point starting from 0% excess (minimum or stoichiometric air, expressed as £=1, meaning there is no excess O2, it is 0%, and CO2% is at its maximum), passing through all values up to infinite excess air (£= ∞), when O2% is 21% or at its maximum, a value that only occurs in reality when there is no combustion.

Parallel to the hypotenuse, the values for each percentage of CO (carbon monoxide) are plotted, with the maximum CO occurring when both CO2% and O2% are 0. This maximum CO value is different for each fuel, as is the CO2% value. The value is higher as the hydrogen/carbon ratio (H/C) decreases; that is, the more carbon the fuel contains, the higher the value (highest in coal and cellulose fuels, decreasing slightly in fuel oil, decreasing slightly as liquid fuels have lower density, and decreasing even further in organic gases, such as natural gas, etc.).

When the CO2% and O2% measurements do not coincide on the hypotenuse (complete combustion), the point of intersection will be in an area of incomplete combustion, meaning there is a percentage of CO present. Generally, the readings do not close at a point, but in a triangle (whose vertices will be CO2-O2, CO2-CO and O2-CO), in this case the center of gravity of the triangle will be taken as the point, that is, the intersection of the perpendicular bisectors of the sides.

To determine the excess air (£) corresponding to a given point, we must first draw a line indicating the points where excess air £ = 1 (excess air equal to 1, minimum air, or stoichiometric air, meaning there is neither too much nor too little air).

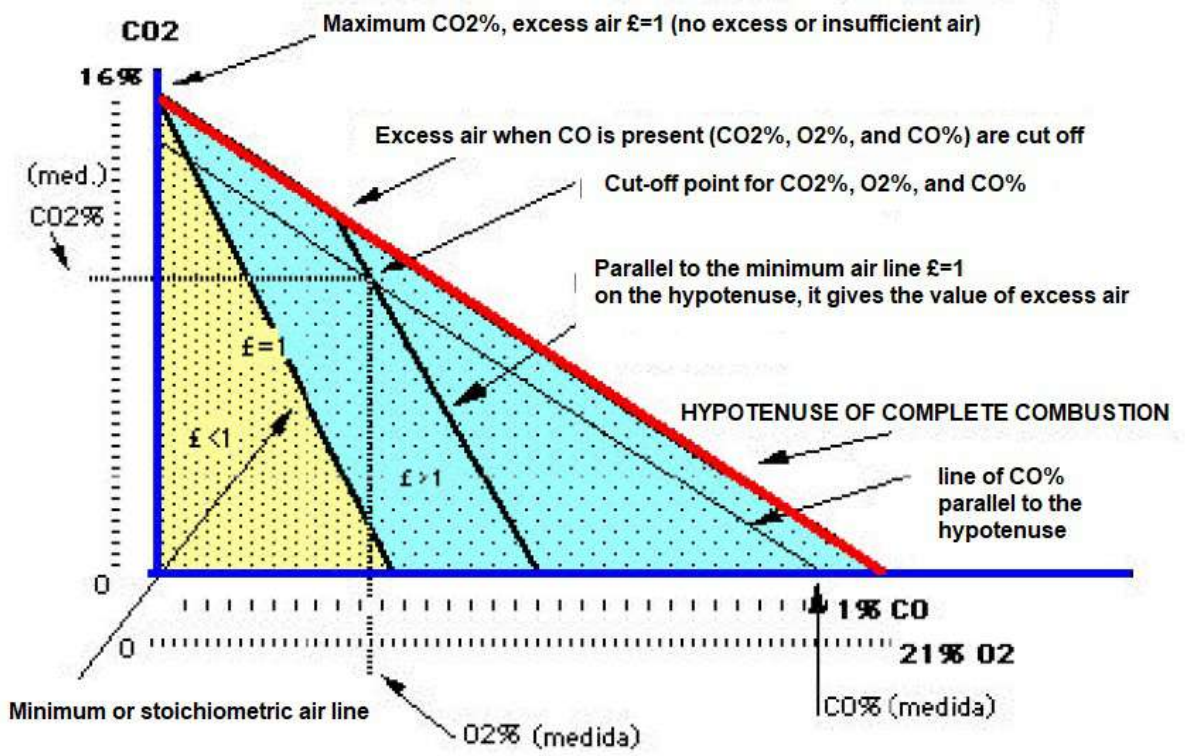
This line passes through the point of intersection of maximum CO2% and O2% = 0, with the other point being the O2% corresponding to CO2% = 0

when the air is at its minimum (stoichiometric).

Once this line is drawn, the triangle will be divided into 3 zones: a - the zone with the lowest x-value, where there is a lack of air (£<1); b - on the line, where there is minimum air (£=1); c - on the O2% values above the line (£>1), where there is excess air (too much air).

Starting with lines parallel to this line, on the right side or where there is excess air, the intersection of these lines with the hypotenuse will give the corresponding excess air at the point inside the triangle.

As can be seen, this triangle represents all the possibilities for combustion (although a "corrected" triangle can be drawn for the CO% values, since it has been detected that when CO is present, there are also unburned combustible gases such as hydrogen; however, we consider these theoretical triangles sufficient for practical purposes, as the desired result should be complete combustion).



The previous sketch indicates the most important parameters in the Ostwald triangle. Remember that to the right of the line of minimum or stoichiometric air (£=1), there will be excess air.

If CO is present when measuring, it is not due to a lack of air, but rather to

incomplete combustion. The CO2% and O2% values will fall in the area Σ>1 (excess air greater than £1). If we measure CO%, it will give a value that increases from the hypotenuse towards the interior of the triangle, with the highest CO% value being the point of intersection where CO2% and O2% are equal to zero (0%).

This maximum CO% value will be higher in fuels with a lower H/C ratio (less hydrogen than carbon).

CHAPTER 5: Operation Part 7 Natural Gas Burners [4b of 5]

4b- CONSIDERATION OF THE NATURAL GAS SUPPLY SYSTEM TO THE BURNER

Given the importance of supplying natural gas to the burner (since combustion chamber explosions are extremely dangerous), a process that requires the use of pressure regulators, it is necessary to have **gas safety shut-off devices.**

Any gas leak entering the boiler combustion chamber through the burner when it is off or shutting down is extremely dangerous, as is the pressure regulator supplying too high or too low a pressure to the burner.

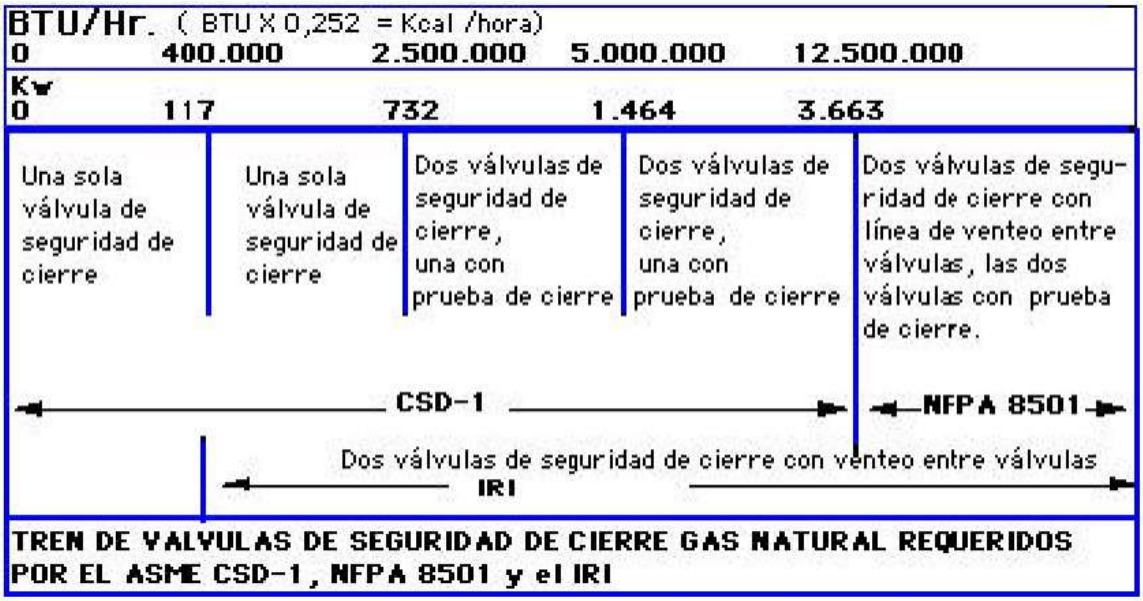
It is also essential to check that the valves are functioning correctly (both by visually verifying whether they are open or closed, and by having the electrical controls checked with a microswitch, using automatic venting devices in case of seat failures, such as low and high gas pressure switches).

In the case of safety shut-off valves; at least two must be installed in boilers of more than 630,000 Kcal/h (2,500,000 BTU/h or approximately more than 1,050 Kg/h of steam), in addition to the natural gas feed regulating valve to the burner (which will be in mechanical relation with the combustion air regulating valve or butterfly, in order to maintain the air/fuel ratio).

The following table lists the standards recommended by the National Board (United States), which incorporates standards from IRI (Industrial Risk Insurers), ASME CSD-1 (American Society of Mechanical Engineers, **Controls and Safety Elements for Automatic Boilers 1992**), and NFPA 8501 (Single Burner Operation of Boilers 1992).

Of course, this is for the USA, but it accurately reflects the safety issues with natural gas boilers.

Original table from “Pequeño Manual del Foguista” and english translation.


BTU/Hr. (BTU X 0,252 = Kcal /hora)
0
400.000
2.500.000
5.000.000
12.500.000
Kw
0
117
732
1.464
3.663
Una sola válvula de seguridad de cierre
Una sola válvula de seguridad de cierre
Dos válvulas de seguridad de cierre, una con prueba de cierre
Dos válvulas de seguridad de cierre, una con prueba de cierre
Dos válvulas de seguridad de cierre con línea de venteo entre válvulas, las dos válvulas con prueba de cierre.
CSD-1
NFPA 8501
Dos válvulas de seguridad de cierre con venteo entre válvulas
IRI
TREN DE VALVULAS DE SEGURIDAD DE CIERRE GAS NATURAL REQUERIDOS POR EL ASME CSD-1, NFPA 8501 y el IRI

BTU/Hr (BTU x 0,252 = Kcal/hora)				
>0 BTU/Hr	400.000	2.500.000	5.000.000	12.500.000
>0 KW	117	732	1464	3663
A single safety shut-off valve	A single safety shut-off valve	Two safety shut-off valves, one with a shut-off test	Two safety shut-off valves, one with a shut-off test	Two safety shut-off valves with vent line between valves, both valves with shut-off test
CSD-1				NFPA 8501
	Two safety shut-off valves with inter-valve venting IRI			
NATURAL GAS SHUT-OFF SAFETY VALVE TRAIN REQUIRED BY ASME CSD-1, NFPA 8501 AND IRI				

In Uruguay, Argentine and European standards have been applied.

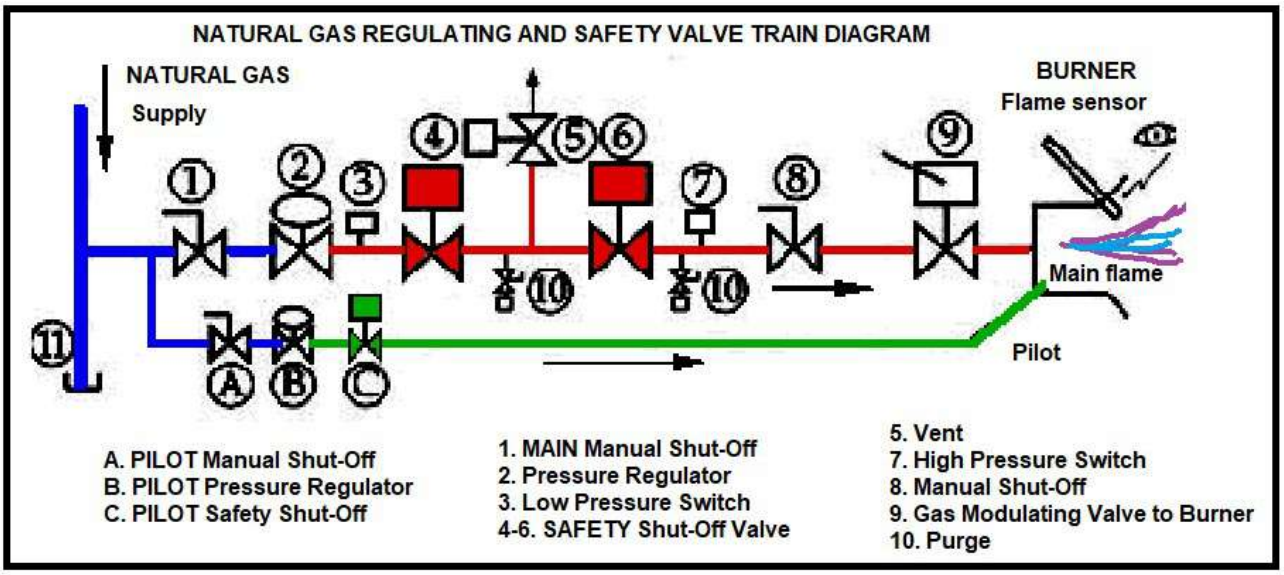
Given the purpose of this manual (general information), we will describe an installation according to American standards (NFPA 8501) to provide an overview of a system with medium capacity. However, we will also incorporate the Argentine standards (ENERGAS) applicable in Uruguay.

Let's now look at a sketch of a natural gas feed train (a simple example with minimal requirements according to some standards; later we'll see a more concrete example, accepted by NFPA 8501 for boilers over 12,500,000 BTU, or approximately a boiler producing more than 5,000 kg/h of steam).

In this sketch, we'll see two safety shut-off valves (which immediately cut off the gas supply, in less than 1 second, to the burner in case of low or high gas pressure failures, control the gas flow to ignite and shut off the

burner, shut off the burner due to low water level, lack of pilot light, lack of main flame, or insufficient combustion air pressure, as well as other controls necessary for startup and maintenance: minimum flame position for startup, closed valves, acceptable electrical voltage, etc.)

And the necessary components (such as those recommended by the IRI standard for boilers with burners over 100,800 BTU). Kcal/h (400,000 BTU/h) equivalent approx. to a boiler of more than 150 Kg/h of steam.



NATURAL GAS REGULATING AND **SAFETY VALVE TRAIN** DIAGRAM

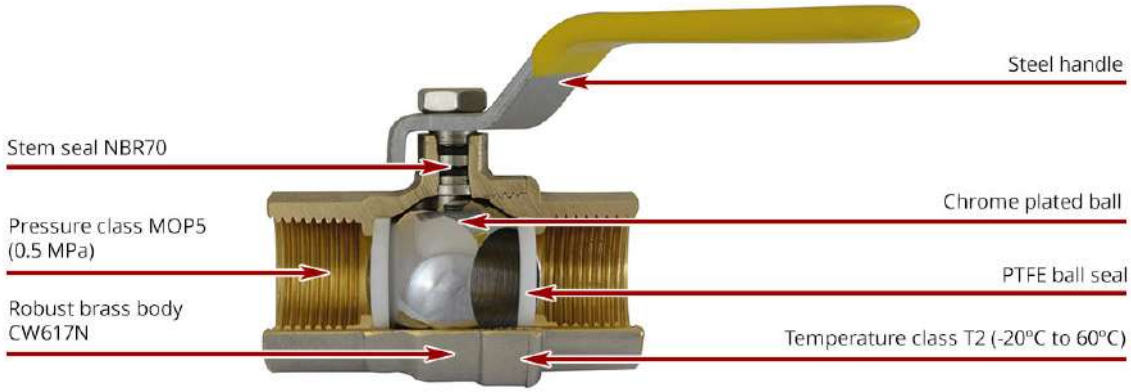
Natural gas arrives through the supply line at a higher pressure than the burner will use. It generally **carries contaminants that can pollute the gas** (such as oxide particles and metallic particles from the pipes and fittings), as well as condensation. There may be a filter, but the important thing is that there is **a vertical drip leg (also known as a collection, storage, and purge plug, shown as #11 on the drawing)** that will collect these debris, those undesirable substances (and can be cleaned periodically).

The gas will then go through two paths;
1) the pilot flame feed (manual valve "A") and
2) the main gas feed (manual valve "1") to the burner (main combustion).

This may vary in some cases. Both supplies will have a manual shut-off valve (the "A" for the pilot and valve No. "1" for the main flame), which allows for safe closure to enable work on maintenance and safe shutdown of the system.

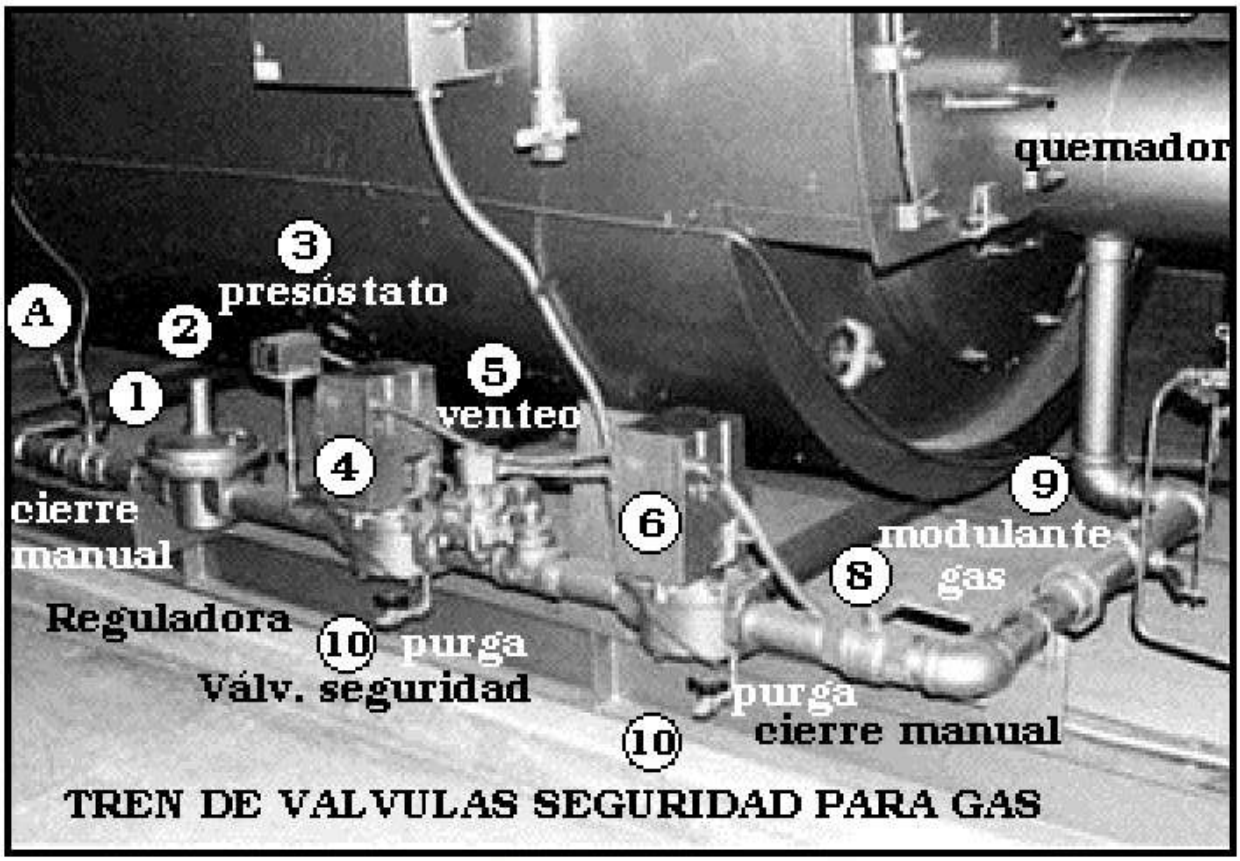
These valves are very important and must be quarter-turn (generally ball

valves suitable for gas, never use water or compressed aire valves).



GAS BALL VALVES, https://www.ferrocompany.com/family-29.html

There may be a pressure gauge indicating the supply pressure and then a pressure gauge in each regulated pressure section.



A. PILOT Manual Shut-Off
B. PILOT Pressure Regulator
C. PILOT Safety Shut-Off

1. MAIN Manual Shut-Off
2. Pressure Regulator
3. Low Pressure Switch
4-6. SAFETY Shut-Off Valve

5. Vent
7. High Pressure Switch
8. Manual Shut-Off
9. Gas Modulating Valve to Burner
10. Purge

NATURAL GAS **SAFETY VALVE TRAIN** EXAMPLE

Of course, outside the boiler room, there must be a manual valve to cut off the natural gas to the boilers (in the same way as in liquid fuel boilers, as well as a way to cut off the electricity).

The pilot light's fuel supply (which consumes very little compared to the main fuel) will also include its manual shut-off valve (A), a pressure regulating valve (B), and a **safety shut-off valve (C).**

Next, the burner's own fuel supply components will supply the pilot flame (generally, the **safety valve (B)** will consist of two solenoid valves, as we will see in a later example, with a vent between the valves if the power rating requires it).

We can divide the operation of a gas ignition pilot into three types:

- **"Continuous pilot"** (which remains permanently lit during service, and even when the main flame is not operating);

- **"Intermittent pilot"** (which ignites automatically each time it is necessary to ignite the main flame, turning off once the ignition time has ended);
and

- **"Intermittent pilot"** (which ignites automatically each time it is necessary to ignite the main flame and remains lit while the main flame is lit).

The gas pilot light accounts for a small percentage of the main gas consumption. Generally less than 3%, although in "small" boilers there may be direct-ignition burners with an electric spark from the main flame. Up to about 100,000 kcal/h, the main flame can ignite at its full nominal value, with a maximum ignition spark of 3 seconds,

then reaching a maximum of about 500,000 kcal/h. to "start" with a lower value than the total capacity, between 30% up to 300,000 kcal/h, and a maximum flame of 20% at startup, up to a maximum of 500,000 kcal/h of power.

For this reason, a burner with "direct start" using an electric spark is not permitted, in order to avoid a "backfire" due to ignition delay. The maximum attempted ignition time of the "electric spark" is no more than 3 seconds (in accordance with Argentine standards).

The same principle applies to gas pilot boilers. The higher the boiler's power output, the lower the percentage of the main flame used at startup, reaching values of up to 20% of the total capacity.

The pilot flame is no more than 3% of the main flame capacity (igniting at 100% of the main flame up to 100,000 kcal/h, 35% of the main flame up to 300,000 kcal/h, and a maximum of 20% of the main flame above 300,000 kcal/h).

The safety gas supply valves open slowly (taking at least 10 seconds up to 10,000,000 kcal/h and opening more slowly thereafter, no less than 20 seconds). However, they close quickly, in less than 1 second, thus preventing a backfire due to delayed ignition. lighting the main flame.

Here, the gas pilot, ignited by an electric igniter, generally has a longer **ignition safety time, lasting 15 seconds up to 300,000 kcal/h**. Above this value, the time decreases to a maximum of 10 seconds.

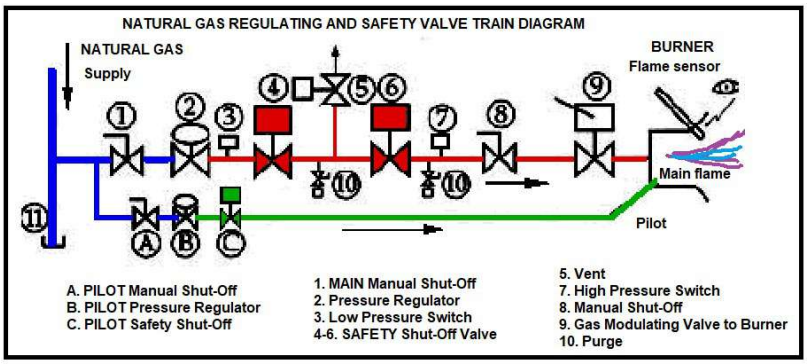
The electric igniter operates for a shorter time, resulting in a gas pilot flame stabilization period of approximately 5 seconds. This allows for monitoring the pilot flame to ensure it is properly functioning before the main flame safety valves begin to open slowly.

For safety reasons, flame control for both the pilot and main flames will cut off combustion at the safety valves, which will close in less than 1 second at 300,000 kcal/h.

Once the pilot flame capacity exceeds 50,000 kcal/h, a double automatic valve safety system with venting between the two valves will be installed.

Reignition or restart of the burner is only permitted if 1 second has elapsed since the flame extinction failure, in boilers up to 100,000 kcal/h. Reignition or restart is not permitted in higher-power automatic boilers (which must shut down in less than 4 seconds, the sum of all flame control and safety valve times).

A post-purge of approximately 15 seconds or more is required to expel any unignited gases.



The main gas supply to the burner will have a manual shut-off valve (No. 1), followed by a pressure regulator (No. 2).

A minimum pressure switch (No. 3) will monitor the gas pressure (switching off the burner if this occurs, but it cannot reset itself; it must be reset by the operator, who will check the supply and regulated pressures before resetting the pressure switch).

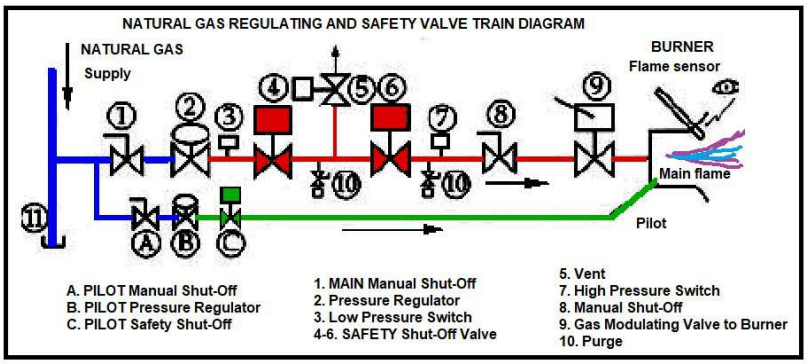
For safety shut-off, there will be two valves (No. 4 and No. 6) that are generally quick-closing (and slow-opening; this slow opening time will increase with increasing fire power, for example: up to 10,000,000 kcal/1000 kcal, no less than 10 seconds of opening time, and above this value, no less than 20 seconds.

This is very important to establish the flame smoothly and not abruptly, which could cause a backfire).

The valve will close in less than 1 second when the fire power requires it, and at a given fire power level (see table above), there will be an indicator showing the valve's status (open or closed).

To ensure that the first safety shut-off valve No. 4 (in case the seat doesn't close properly) there will be a vent valve (No. 5) that will open each time valve (No. 4) closes (venting the gas trapped between the two safety shut-off valves).

This way, if the second safety shut-off valve (No. 6) fails to close. Thanks to the venting, since there is no gas pressure between the two shut-off valves, the gas will not pass through valve (No. 6) to the burner, but will instead be released to the atmosphere through the vent (which can be dispersed or burned in a special device in a safe area, outside the boiler room).



After the second safety shut-off valve, there will be a pressure switch (No. 7) that will shut off the burner if the gas pressure exceeds the set point (it also needs to be manually reset, since once it shuts off the burner, it will not allow it to restart if the boiler operator (does not reassemble it manually).

Next, between the fuel line and the burner, there will be a manual shut-off valve (No. 8), which allows manual gas shut-off to the burner's gas regulator. (This allows testing of the regulation and safety shut-off system, including the pilot light, without the burner being ignited or supplied with gas.)

Next, there will be a valve that regulates the natural gas to the burner (No. 9), according to the gas requirements based on the steam boiler pressure or the hot water boiler temperature.

There will be drain valves in the lower sections of the fuel line (No. 10), which allow condensate to be removed (or gas leaks can be tested by observing the bubbles in a container of water. A flexible tube is connected to the valve, and the end of the tube is submerged in the water in a jar. Based on the number of bubbles per minute, a maximum permissible leak limit can be established.)

In smaller boilers, "monoblock" valves with leak testers for the main valves may be available.

The burner will also have the necessary safety features (monitoring of the pilot and main flames, cutting off the gas supply by closing safety valves No. 4 and No. 6 within 4 seconds of flame failure, totaling all times, but the valves themselves must close in less than 1 second).

Adequate purging times to properly vent the gases before ignition (generally no less than 4 air changes inside the combustion chamber and pipes, or 90 seconds, with the damper open 60%) and a post-purge upon shutdown (venting the combustion gases after extinguishing, preventing their

accumulation inside the combustion chamber, as these gases may contain unburned fuel).

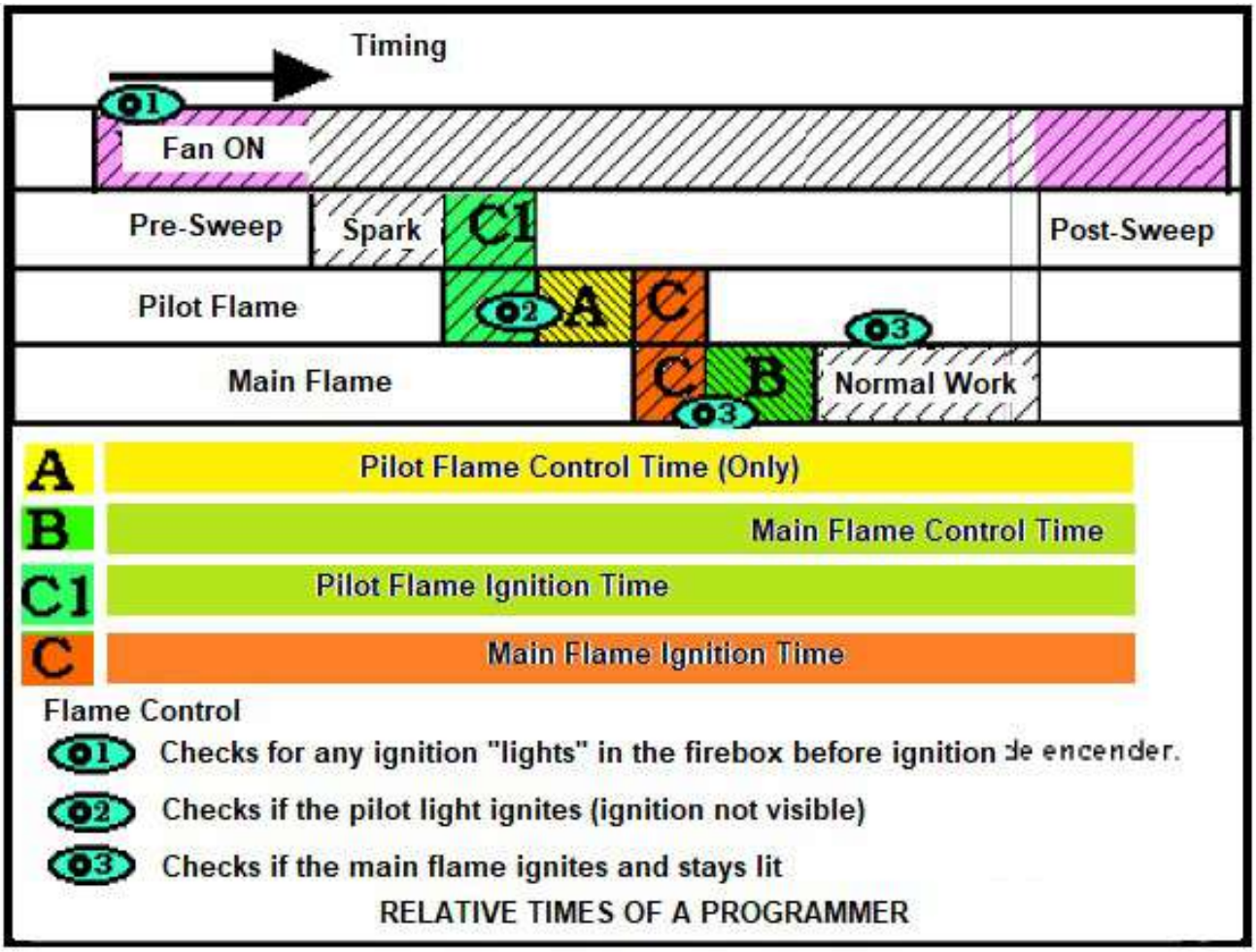
To this must be added another series of "tests" or "checks" that the programmer must and can perform, both while the system is running and stopped, and especially before proceeding to "start" it up (such as a microswitch indicating that a safety shutoff valve is closed, that the system is in the minimum starting position, or that the modulating motor has set the air control and gas valve to the minimum, generally less than 25% of total capacity, that the photocell does not detect any flames or visible fires inside the combustion chamber, that there is air pressure in the burner's air supply, etc.).

And then all the other control and safety elements of the boiler itself (control pressure switch or thermostat, maximum safety limit pressure switch and thermostat, water level sensor (generally dual), etc., such as the "interlock" systems for the circulation pumps in hot water boilers or the "sensors" indicating oil circulation in hot oil boilers). thermal).

COUNTER EXPLOSION IN NATURAL GAS BOILER

As we have seen, this system allows us to test each of the parts in order: the main or power flame train, without feeding the burner (closing No. 8, and without the "pilot" flame by closing A), test only the pilot flame igniter (and with it the sweep time and the sweep mechanisms and minimum and maximum air position, the safety microswitches of "safety valves closed", no presence of ignition sources before ignition, etc.), then test the gas ignition "pilot" in its "safety time" (that is, with the electric igniter already cut off),

But with the pilot gas flame lit (A in the diagram below), which if the photocell doesn't "see" it, the burner cuts off the pilot flame in the "safety" seconds and the burner remains "locked"), and then enabling valve No. 8 of the main gas supply, the entire burner is tested (in which the main flame will have its "safety time" (B in the diagram below) in which the auxiliary gas pilot flame has already gone out.



In short, the "programmer" will perform a series of checks depending on the brand and standards it complies with. Generally, before starting an ignition cycle, it performs a series of checks:

Once the steam pressure switch (or hot water thermostat) "closes," giving the command to ignite the burner (but the level controls, both the pressure limit switch, and other limits, such as closed gas safety valves, safety valve leak testers, etc., must also be enabled), the following occurs:

1- that the **air supply fan is running and there is combustion air pressure**;

2- that there is **no "visible" flame** to the flame detector from any point inside the combustion chamber (note, it must be visible to the flame sensor, whatever it may be; therefore, there may be flames in non-visible areas, which can cause explosions, because the boiler is dirty with soot from having operated on fuel oil or due to poor combustion of the natural gas itself);

3- Check that the **gas supply valves are closed**;

4- Perform a **purge of the combustion chamber and flue area** with several air changes (no less than 4 changes or 90 seconds with the air supply fully open), after verifying that there is air pressure in the burner's air chamber (air pressure sensor);

5- Verify that the purge was performed with the **air supply fully open** or at least 60% open (using a fully open microswitch);

6-a Before starting the flame ignition cycle (spark igniter, auxiliary pilot, and main flame), check if the **air and fuel modulation valve are at the "minimum start-up"** setting (generally less than 25% of the burner's total power).

6-b **Light the electric igniter for a few seconds** (first, depending on the model, the igniter alone, usually for about 3 seconds), then cross-light the auxiliary pilot gas to ignite it. In any case, the flame sensor must not detect the electric spark (or any other heat source) at any time to avoid errors.

6-c **Light the auxiliary gas pilot flame** (from a cylinder or piped gas, which, monitored by the flame sensor, should generally ignite for a maximum of 3 to 5 seconds (time C 1), or according to regulations; sometimes cylinder gas is preferred for the pilot because it has a "hotter" flame and is more visible). Turn off the igniter, leaving only the gas pilot under the control of the flame detector for a few seconds (check if the pilot flame is stable, generally for a maximum of 5 seconds (time A), depending on many factors).

7- Then the **main flame is lit at the "minimum" setting** (ensuring that the minimum and maximum gas pressures are within operating parameters from the moment the main flame is enabled, the safety valves open slowly and the gas modulation valve is at its minimum, which is usually less than 25% of the total capacity),

and **the pilot flame goes out after a few seconds**, making a "crossover" of contact time with the main flame's gas (from 3 to 5 seconds, depending on time C) so that the main flame has a relatively short time to ignite.

If it doesn't ignite immediately (the flame sensor detects it in less than 1 second to a maximum of 3 seconds; if the flame is not detected, it cuts off the gas safety valves, which close in less than 1 second),

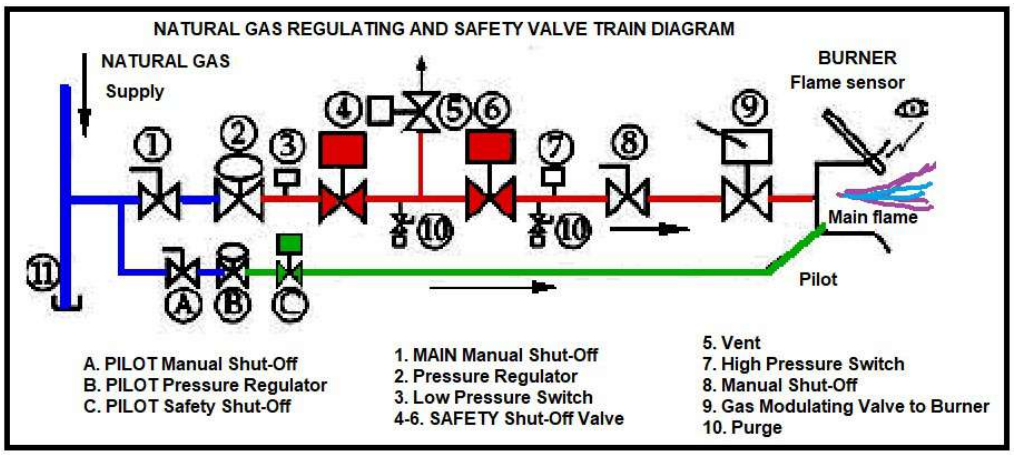
the burner shuts off and performs a "post-purge" to "sweep" away the unignited gases (the burner remains "locked" until the operator identifies the cause of the failure and then **T**

he programmer then "resets" itself, thus becoming aware that there is a fault. Faults will be indicated in different ways depending on the programmer (on an electronic display, or by indicating when the lockout occurred if it is a "rotary" programmer, etc.).

If the burner ignited normally, there is a waiting period for the flame to stabilize (usually 3 to 5 seconds, time B). Only after this period does the burner begin to modulate, **drawing fuel according to the command from the pressure switch or modulating thermostat.**

When the boiler pressure causes it to shut down due to a "steam pressure cutoff" (a pressure switch) or its temperature (a thermostat), the burner shuts off (before reducing to the minimum if it is modulating) and performs a "post-purge" to expel any remaining gases. Since the mixture is "lean," this can cause a "delay" explosion.

In this case, the burner is ready to begin a new normal ignition cycle.



Gas shut-off safety valves (4) (6), usually consisting of 2 valves (or a double valve in the same body in small boilers), open "slowly" (several seconds) and must close "quickly" (usually less than 1 second).

These valves must have a "vent" (5) between them to the atmosphere or to a vent manifold that carries the gas to a safe place (which will go to the atmosphere if possible or where it is burned with a pilot flame) when they are closed, so that there is no loss of gas into the home.

Other systems, instead of vents, have a valve leak test system (there is more than one test system: one uses a small gas pump to raise the pressure a few millibars above the normal pressure between the two closed valves and uses a pressure switch to monitor whether the pressure drops within a certain time;

another consists of testing the two safety valves step by step, checking that the pressure does not drop between the valves within a certain time. This tests the valve closest to the burner, or, by "emptying" the gas between the valves, it checks that the pressure does not rise due to a leak in the first valve).

In "small" burners, the valves may be in the same "body," with the test or vent system included, etc.

It is very important that the safety valves for the main flame (4) (6) and the pilot flame (C)do not allow gas to enter the combustion chamber under any circumstances if they are closed, as this could cause a combustion chamber explosion.

Once the burner is properly lit, the air-fuel ratio must be adjusted throughout the burner's operating range.

Taking care **not to exceed the maximum combustion power** as this can cause the tubes, which are either mandrel-grooved or mandrel-grooved and welded to the hot plate, to loosen.

Remember that the natural gas flame is not very visible for visually adjusting the air-fuel ratio.

It is advisable to have instruments that measure excess air (between 10% and 20%) and ensure good combustion by measuring unburned gases (or carbon monoxide, CO, which should be less than 400 ppm, approximately 0.04% CO, although a good burner should show a near-zero CO reading).

Unburned gases can be present due to insufficient air or a combustion problem (poor gas-air mixture, combustion chamber too small for complete combustion, very cold flame, etc.).

Remember that the air-fuel ratio (excess air relative to gas) changes if the gas regulator pressure changes (if the gas pressure rises, there will be less air, and if the gas pressure falls, there will be excess air).

Natural gas generally doesn't produce smoke from the chimney, but it can produce soot (very fine and highly insulating, which can even contribute to a fireplace explosion).

CHAPTER 5: Operation Part 7 Natural Gas Burners [5 of 5]

5. Personnel must be carefully instructed and trained.

Everything necessary in terms of time and investment in instruction and training (both simulated and real) is the best investment when using gas burners. Since everything seems easy at first, if there are no problems, over time carelessness develops due to a lack of training, which can lead to painful accidents.

PROBLEMS WITH DUAL-PURPOSE BURNERS (Fuel Oil and Natural Gas)

In Uruguay, the natural gas supply is generally subject to interruptions, especially when a special tariff is not paid.

This means that companies must have "dual" burners (that operate on fuel oil or other liquid fuels and on natural gas).

The problem is that when using fuels like heavy and medium fuel oil, the nozzles or openings in the gas rings (through which natural gas is supplied inside the fireplace) can become clogged (dirty with slag and fuel that obstruct the gas inlet holes), and residues of fuel oil, slag, or soot may also remain inside the fireplace.

This makes starting the fireplace with gas dangerous, so much so that without verifying that the gas inlets are free of obstructions (or that there may be ignition sources inside the fireplace that could ignite an explosive gas mixture during a delayed ignition, in addition to possible distillations of residual fuel oil that release flammable gas with the residual heat).

This obstruction of the gas inlet nozzles to the combustion chamber, when they are "blocked" or "partially blocked," will not supply gas adequately at the moment of "start-up" (when the burner is in the "start" position, after purging and returning to the "minimum start-up air" with the modulating gas valve at its minimum setting).

This causes the gas not to ignite immediately and stably, given its low pressure, due to the small flow rate of the low load or "start-up" (generally less than 25% of the maximum load and with the safety valves opening slowly).

The gas enters an area where the pilot light cannot ignite it.

This can produce an unignited mixture inside the combustion chamber, a "lean gas" mixture (a low gas-to-air ratio), which ignites violently, causing a "combustion chamber explosion."

This situation is exacerbated if the remaining fuel oil is vaporizing combustible gases (distilling from the heat after the burner is turned off, fuel deposits that have fouled the combustion chamber and pipes), which, combined with the incoming natural gas, increases the likelihood of creating a potentially explosive mixture.

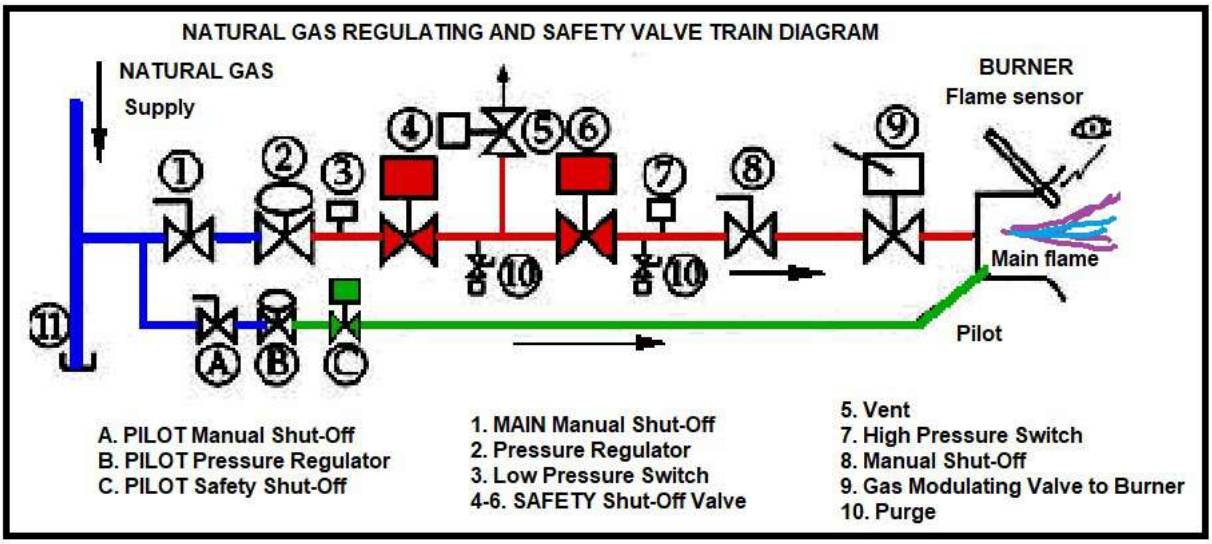
This gas mixture that hasn't ignited doesn't necessarily ignite because the combustion chamber "fills" and the pilot light ignites it. It can ignite from any heat source that is "latent" under the soot and is "rekindled" by the air purge at the start of the burner cycle. **A heat source above 600°C (1112°F) is enough to cause an explosion.**

Unfortunately, this has already happened in Uruguay, with the stokers, boiler operators, paying the price for "inexperience." They haven't received training from the burner or gas suppliers. These companies should have provided adequate training to the stokers who operate these types of burners.

I believe it is very important that boilers that have burned fuel oil or must operate alternately with natural gas be kept clean of soot and slag deposits (I would even advise that after "brushing" the soot, before converting to gas, they be thoroughly "washed" with slightly alkaline hot water—soda—since fuel oil residue is generally acidic and causes corrosion under the conditions in which gas boilers operate: condensation occurs when the boiler is cold).

Each time gas is burned again, after a period of operation with F.Oil, perform a "large" purge (with the air intake and supply air wide open) for several minutes to ensure that the remaining liquid fuels are burned or vaporized, or that any "hidden" combustion spots are extinguished, before switching the burner to gas operation (checking that the gas nozzles are free of slag or blocked).

The pilot flame is supposed to ignite safely after a sweep of four or more times across the entire combustion chamber and boiler tubes.



Alternatively, a 90-second sweep with the fan at no less than 60% of its full opening should be performed, and there should be no ignition source present before the pilot flame ignites. This is enabled by the "minimum air" setting for startup, allowing the main flame to ignite without being blown out.

The pilot flame may remain lit for up to approximately 10 seconds and must be detected by the photocell. A special gas sensor, usually UV-based, must not detect the electric spark that will be established a few seconds earlier.

These photocells must, in some cases, be "self-checking," and there may be more than one flame detection system in combination, such as an "ionization" rod. During this period, it is ensured that the pilot flame is correctly ignited or stabilized (for about 5 seconds, once the igniter has turned off).

Then, when the main gas supply valves are slowly opened (these are slow-opening and quick-closing), the modulating gas supply valve will already be open to less than 25% of its maximum combustion capacity (depending on the total capacity).

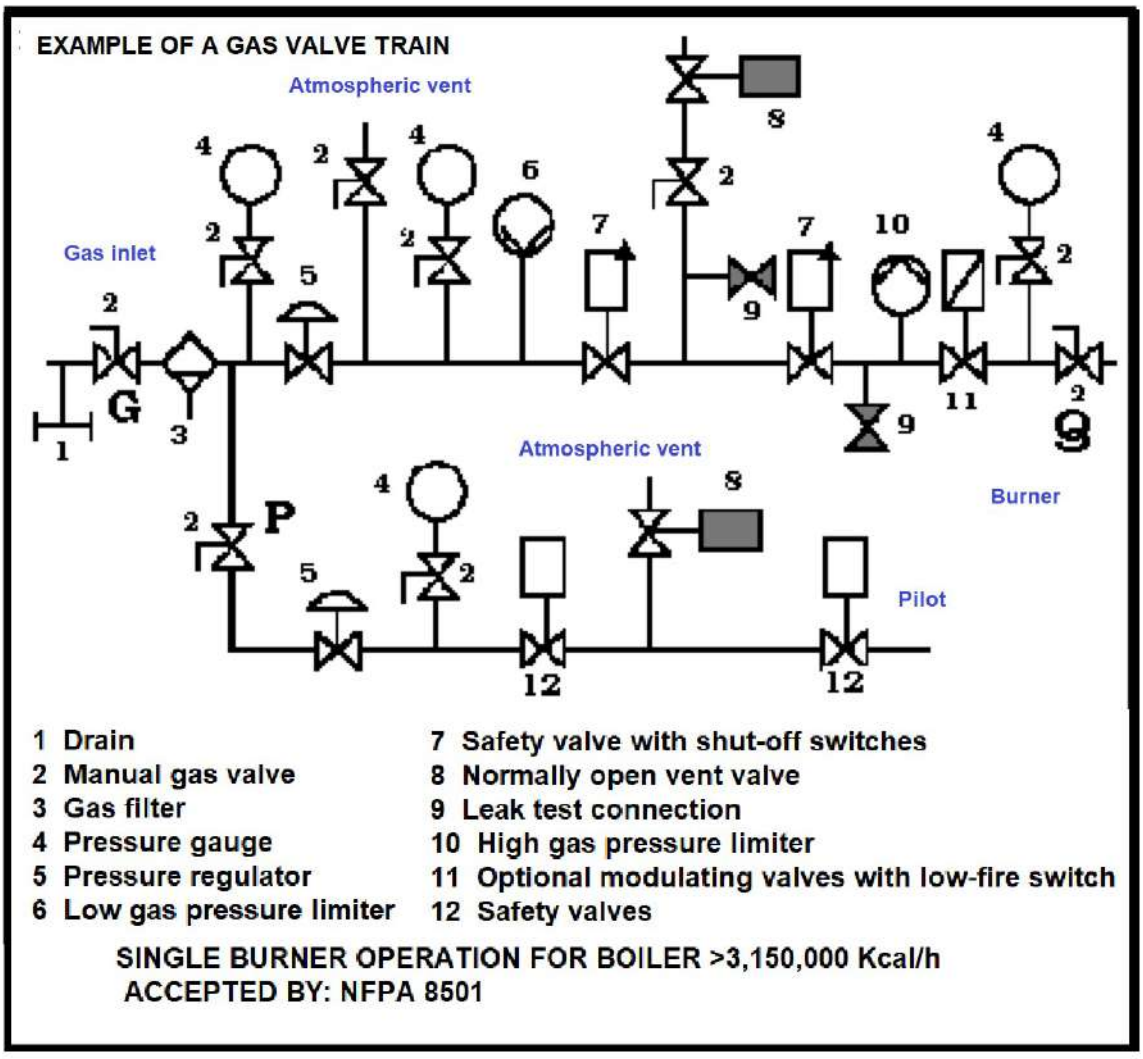
The main flame will have between 3 and 5 seconds to ignite with the gas pilot; otherwise (that is, after this period the pilot flame must be extinguished to ensure that the photocell only detects the main flame).

So, if the If the photocell does not detect the main flame once it has stabilized and is operating independently, it must immediately close the safety gas shutoff valves in less than one second. The main safety gas shutoff valves must close.

There are generally two valves, with a valve in the "middle" that automatically vents the gas between the two shutoff valves (in larger boilers), or a valve leak detection system. This ensures that gas cannot continue to be supplied to the burner due to a leak or failure of the shutoff valves. These latter valves are specialized and must have a mechanical indicator showing their open or closed status.

Remember that the valves supplying gas to the burner open slowly and close quickly (to prevent an abrupt gas supply and rapid closure upon detecting a fault: lack of flame, lack of combustion air, etc.).

Given the danger of switching from fuel oil to natural gas, it is advisable to check that the gas supply nozzles are in good condition. Ensure they are unobstructed and clean, or if they were protected while the burner was operating on fuel oil, check them one by one, as even those closest to the pilot light can become clogged, hindering the immediate ignition of the main flame with natural gas.



It is advisable to perform a complete burner check (or as recommended by the boiler or burner manufacturer or the relevant authority):

The following is an example of a test procedure, not necessarily the one indicated for a specific burner.

Therefore, it is advisable to follow the instructions provided by the boiler or burner vendor.

1- First, without supplying gas, by closing the gas inlet valve to the safety train (Inlet No. 2 G), the system should detect the lack of gas pressure and shut down due to low gas pressure.

Then, opening this valve and closing the other two manual valves (manual gas valves #2 at the burner inlet Q, i.e., the one closest to the boiler burner, and P, i.e., the one that supplies gas to the pilot, as indicated in the previous diagram), for both the pilot flame and the main flame,

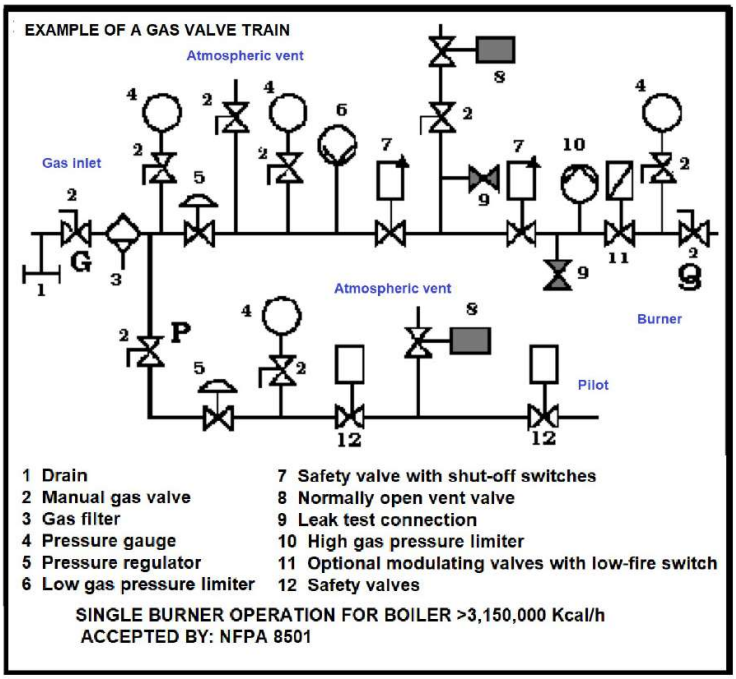
This will simulate the burner being able to ignite due to gas pressure, but not actually igniting because the gas inlets (#2, Q, and P) are closed. This will allow us to verify the timing and method of purging the combustion chamber with air, without igniting the burner (ensuring that there are four volume changes in the combustion and flue gas chambers, or 90 seconds with the air supply open at least 60%).

Verify that the burner moves down to the "minimum air for start" position, verify that the igniter produces a sufficiently powerful spark, and observe, after the pilot flame has been established, whether the operation is canceled due to "lack of flame."

During this trial period, two further tests can be performed:

Disconnecting the air pressure switch (the one that enables the system by detecting combustion air pressure) will lock the burner (the fan may not turn off, but the cycle will be interrupted, the purge will not begin, or the cycle will be suspended if the air duct connection is disconnected, locking the burner, which will then need to be replaced by the boiler operator).

Test if the burner is locked due to the presence of a flame (in this case, remove the photocell and expose it to light before the igniter starts). When the photocell detects light, the burner will lock.



2- Test again with only the pilot light enabled (by opening pilot valve #2P) after completing all the previous steps. Ensure the pilot light ignites for approximately 10 seconds (depending on the burner) and is detected by the photocell, allowing the main gas safety valves, #7, to open (these valves will function, but will be disabled by closing the manual gas inlet to the burner, valve #2Q, meaning no gas will reach the burner).

Verify that the gas pilot light ignites within a maximum of 3 to 5 seconds (the time it takes for the spark plug to ignite the gas pilot). If the gas pilot does not ignite, the flame detector will abort the operation and shut off the burner.

If the gas pilot light ignites, the programmer will let the gas pilot light run on its own for about 5 seconds, without the electric igniter, to observe the stabilization of the gas pilot flame (to see that it is lit correctly). However, if the pilot flame goes out during this stabilization time, the photocell "aborts" the operation due to "lack of flame" (the "pilot flame" has gone out and there is no main flame; the quick-closing valves, No. 7, must close in less than 1 second; the burner goes into "lockout" mode and the boiler operator must "reset" the system).

3- Only at this point should the main manual gas valve to the burner (No. 2G) be opened, thus completing the ignition process.

4- An additional test is to close manual valve No. 2Q with the burner lit and verify that the burner shuts off due to lack of flame in less than 4 seconds

(the sum of the times between the flame detector registering the lack of flame, which should be less than 3 seconds and is currently less than 1 second, and the closure of the safety valves, which should be less than 1 second).

STAND SIDEWAYS IN ALL OPERATIONS, SO THAT IF THERE IS A HOME EXPLOSION, IT CAN "RIP OUT" THE BURNER OR OPEN (or "rip out") THE CLEANING "COVERS" OF THE SMOKEBOX, CAUSING IMPACT DAMAGE TO PEOPLE AND PROPERTY.

In this case, it is important to prevent these elements from impacting the gas pipes, as this would cause a fire with very serious consequences.

Although there is supposed to be protection against excess gas flow or pressure loss, which should shut off the gas, in some cases there is a quantity of gas in the pipe between the valve train and the pressure regulators and high and low pressure shut-off valves of the supply line, which are generally located away from the boiler room as required.

The safety, regulation and control valves for the gas (corresponding to the burner) should be located as close as possible to the burner (this ensures that the burner does not have to wait for the air to be "purged" from the pipe, which delays ignition and increases the risk of a bad ignition) and protected from the "impact" of a combustion explosion (placed to the side of the boiler and not facing it).

In summary (follow the instructions of the gas burner and/or boiler supplier):

Check (clean) gas supply nozzles.
Keep the boiler free of soot and slag from operation with liquid fuels (and with natural gas itself).

When switching to gas, perform a thorough purge of any remaining fuel oil, and carry out step-by-step tests on each burner stage (and since this is not a life insurance policy, do not expose yourself to the critical area that could be affected by a combustion explosion).

Hasty maneuvers are the most dangerous; take your time!

BOILER CONVERSIONS TO BURN NATURAL GAS

One of the problems when converting a boiler to natural gas is the temperature of the metal (mandrel and/or welded) of the tubes in the first tube pass to the plate in contact with the combustion chamber, which we generally call the "hottest plate" (whether it's a dry-bottom boiler, the most problematic, or a wet-bottom boiler, a box boiler, or a semi-wet-bottom boiler with a rear tube "cap").

The metal of the plate and the "tube tips" should not exceed 425ºC (800ºF). In other words, in the "hearth tube" of fire-tube boilers, the flame must "dissipate" its heat in such a way that it reaches a temperature that does not heat the metal beyond 425ºC (with scale-laden boilers, and there are some, this can be a serious problem, since the metal does not cool properly). Otherwise, there is a risk of "burning" the metal (cracking the "tube tips", loosening the mandrels, or cracking the tubes and the plate).

This is further aggravated if the mandrel work and welding of the tubes to the plate are "poorly done" meaning that metal parts protrude into the gases (the length of the tubes outside the plate is greater than permitted; generally, it should not exceed 3 mm if they are mandrel-drilled and welded, but if they are only mandrel-drilled, it is advisable that they be "flared,"

that is, the end of the tube is "upset" with a "rounded" finish, a task that was done by hand or with a pneumatic hammer with a tip shaped like the "flap" end) or they have a poor "finishing finish" (edges, cracks, or weld "rings").

It is clear that the temperature of the gases at the end of the combustion chamber has already transferred a significant portion of the heat. In liquid fuel boilers (such as oil-fired boilers), given the high "luminosity" and short duration of the flame, approximately 40% of the heat is generally transferred. However, with natural gas, the more diffuse, less luminous flame results in less heat transfer (around 30%).

This means that boilers burning natural gas, for the same steam production "power", will have a slightly higher chimney temperature than when burning a liquid fuel such as F. Oil (for the same "load" and excess air, i.e., the same air/fuel ratio).

Of course, the hearth must have adequate dimensions, both in diameter and length, as well as the connection of the hearth pipe to the first pipe pass (box, hood, dry bottom), for maximum combustion power.

SOOT CAUSED BY NATURAL GAS

There is an English standard that establishes a theoretical calculation formula to determine an approximate temperature of the gases at the inlet of the first tube pass (the outlet of the combustion chamber and the rear flue box between the combustion chamber and the first tube pass).

This calculation formula is based on the maximum combustion power divided by the surface area of the combustion chamber plus the corresponding bottom surface area (wet, with a hood, or without, as in the case of a "dry bottom"). This ratio is raised to a power fraction and multiplied by a factor.

If the gas temperature exceeds 800°C (1472°F), it is advisable to measure the temperature of the metal of the tubes and the back plate (it should not exceed 425°C (797°F). If it is higher, ceramic shields should be installed or the maximum combustion power reduced).

If the value is greater than 1200°C (2192°F), the maximum combustion power should be reduced below 1200°C. 2192°F. The English standard is BS 2790.

In short, when the boiler switches to burning natural gas, the maximum combustion temperature must be monitored to prevent the metal from exceeding 425°C (797°F) in that area (mandrel-bore and welded boilers can operate at a gas temperature of around 1200°C (2192°F), but mandrel-only boilers are more sensitive, so this temperature should be lower or a ceramic shield should be placed on each tube).

One way to control this maximum combustion is to monitor the flue temperature (with the boiler clean of soot and scale) to ensure it matches the value specified by the manufacturer in the design (since the temperature of the metal of the flue tube, inside the boiler, is not easy to measure and is practically impossible).

Otherwise, ceramic heat shields (tubes or nozzles) will need to be installed to protect this sensitive area from excessive heat.

This effect caused many "headaches" in countries that were converting their solid and liquid fuel boilers (since many boilers "loosened" the mandrels or cracked the "hottest" plate) **when switching to burning natural gas**, which appeared on the market after these boilers were designed for the classic fuels (the new boilers will be specially designed for gas and backup liquid fuels).

An increase in chimney temperature can indicate several things:

1- Excessive combustion, which is very risky (especially with mandrel-shaped flues).

2- A boiler clogged with soot, which poses a risk (and can lead to financial loss due to reduced efficiency), but there may also be other risks, such as an increased risk of a fireplace explosion.

Although it may seem strange, if the boiler operates with insufficient air, a poor natural gas-air mixture, or a very cold flame, natural gas can produce soot that insulates the boiler in the same way as the soot produced by liquid fuels (it is more insulating than the soot from liquid fuels due to its low density, a powder almost like "smoke black"), even though we won't see "smoke" coming from the chimney.

The fumes are generally not soot, but rather "tiny droplets," like a "mist," of organic matter, which are present in liquid fuels and some solids. In natural gas or other gases, it can appear as "sooty smoke," which looks more like a

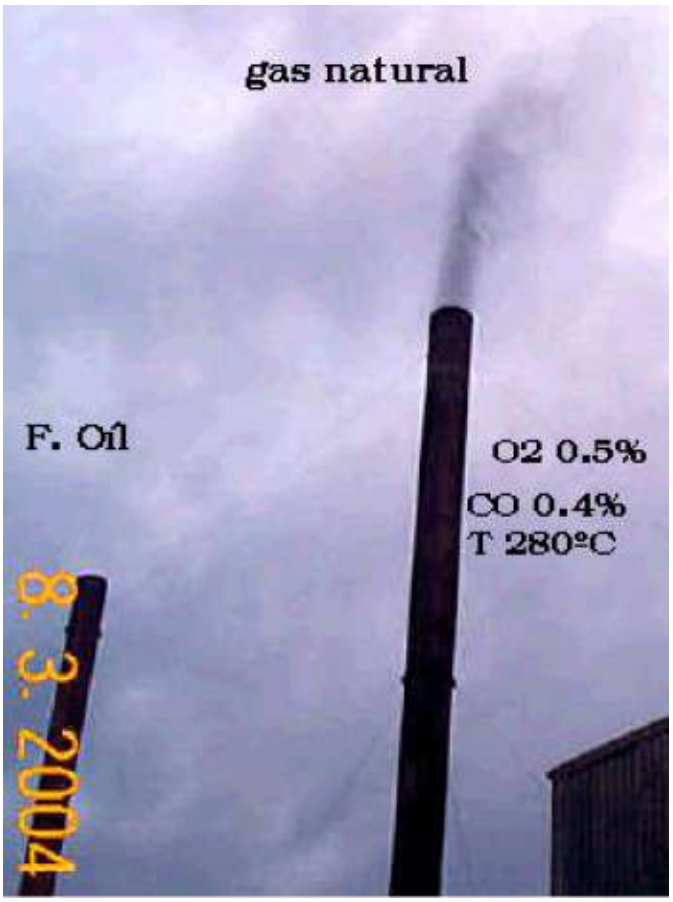
"shadow" when held up to the light, except that the expelled gases will be somewhat more opaque when held up to the light.

The risk may be a back-explosion, given that the gases are rich in "unburned gases" which are added to a possible "mixture" with soot dust (an extremely light soot, like "carbon black", but agglomerated in an organic form), and this mixture can ignite at any point in the boiler (including in the smoke boxes or chimney, due to a spark or combustion focus in the "soot" itself that is activated by the "sweeping" of the start-up).

3- Scaled boiler: there is a risk (danger of burning the metal due to insufficient cooling).

4- Excessive air intake: there is a risk of overheating in the mandrels (and a waste of money, as we are heating air that we don't need).

5- In some cases, combustion shift (a lack of air should lower the temperature in some cases, but in others it may be the cause of the flame shifting towards the "back" of the fire tube, or a poor air/fuel mixture, causing temperatures to rise in the area of the plate, at the entrance of the first tube pass).



In summary:

The behavior of the gas should be constantly monitored, just like any other fuel.

However, there's a tendency to think that once natural gas is burning, there's no need to clean the boiler of soot or observe the flame (since there are no visible fumes or noticeable flame colors), because with gas "nothing's wrong."

This isn't the case. With natural gas, we must be very attentive precisely because of this lack of "signals" that things are going wrong.

A change in gas pressure, or any alteration to the burner component such as a dirty turbine (the fan impeller), which must be cleaned to maintain efficiency, can cause a lack of air.

Other issues, such as dirty air controls (i.e., dirty dampers or silencers), can lead to this problem. This lack of air will allow soot to form (a fouling of the heat transfer surfaces, which will be noticeable as an increase in chimney temperature or higher gas consumption, but will not produce smoke, except for a darkening of the flue gases if the soot is expelled).

The flame will change in appearance, becoming more visible (darker and more reddish in color).

The natural gas supply pressure must be as stable as possible; otherwise, we risk the air/fuel ratio changing continuously as the pressure fluctuates. It's even possible that when gas pressure increases, there will be insufficient air, causing the burner to modulate for the same power output.

This results in both the gas and air valves closing, but since the same amount of gas is entering due to the higher pressure, less air will be available. This will cause combustion to enter an air-deprived zone, leading to the formation of CO, unburned gases, and even soot.

In short: we must remain vigilant when burning any fuel, but especially gases, which are not very demonstrative of combustion changes (inconspicuous flame, practically no smoke formation, etc.). This also applies to cellulosic fuels (firewood, husks, etc.).

CHAPTER 5: Operation Part 8 BURNING

THE RICE HUSK (RICE SHELL)

Rice husks, with no other practical uses of value (in this country), are a fuel with a fairly good calorific value at 10% moisture content (water basis): a HCV of 3,100 kcal/kg (5,575 BTU/pound) and a LHV of 2,800 kcal/kg (5,036 BTU/pound).

The major problem is that, when burned, they contain a large amount of ash (mainly silica, more than 20%).

The most common silica we see daily is sand. When this silica burns at the high temperatures at which the husks are burned, it forms small, semi-molten flakes with a whitish, glassy appearance; it is very volatile and abrasive.

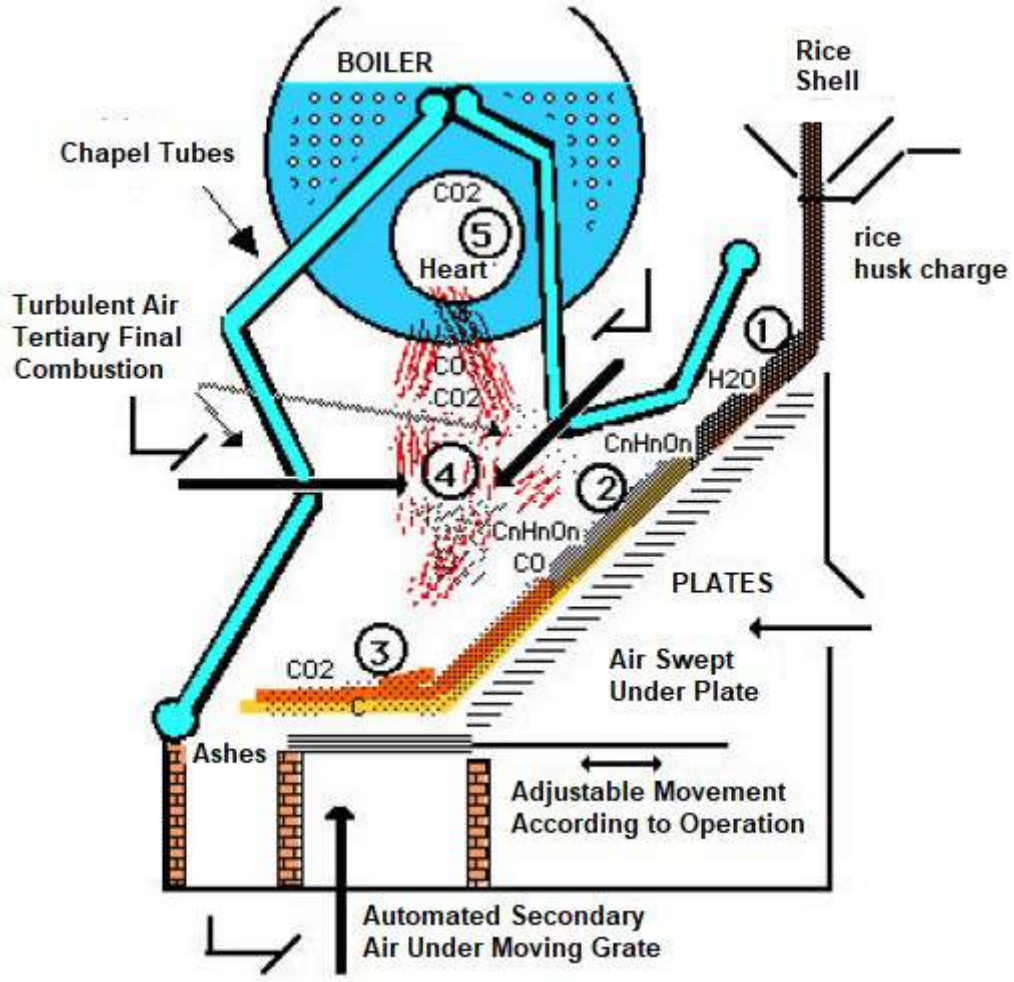
This silica is especially abrasive with the gas flow inside the boiler, causing erosion corrosion in the areas of change of front, aided when the chemical conditions of combustion are not adequate and also with the presence of a small amount of sulfur in the shell that causes an acid-abrasive type of corrosion.

The moisture content of rice husks used for burning is low, approximately 10%. This low moisture content is what makes their calorific value almost equal to that of firewood with a 25% moisture content (which rarely falls below 20%).
The carbon content is around 40%, and its hydrogen content is low, less than 5%.

As we have seen, with its calorific power, it competes perfectly with firewood, but its problem is combustion: **a large amount of ash, the husk and ash are volatile (a problem of abrasion and atmospheric pollution), but also complete combustion must be achieved, so that no unburned gases go through the chimney gases, nor does a quantity of calcined carbon remain in the ash (a black-looking ash, instead of a whitish ash).**

Its combustion has been approached in various ways: in beds (as in Uruguay), in high-temperature chambers (cyclones or torsion chambers, USA, Brazil, etc.). In Uruguay, the company TURBOFLOW URUGUAY S.A. has been building combustion bed boilers for over 20 years (6 to 10 ton/h fire-tube boilers with shrouds).

Let's look at a schematic representation of a rice husk combustion bed:



This rice husk combustion chamber consists of a combustion chamber with finned tubes (welded to the tubes) on the top and part of the sides, mechanically sealing the exhaust gases or the air intake.

These tubes are fed with boiler water at their bottom via headers (MANIFOLDS). At the top, there is one or two headers for the outlet of the circulating water and any steam that may form (this header also has steam relief tubes at its top).

At the top, it connects to the (corrugated) firebox tube, where combustion is completed inside the fire-tube boiler. The front wall and part of the back wall of its internal structure are made of refractory material (brick).

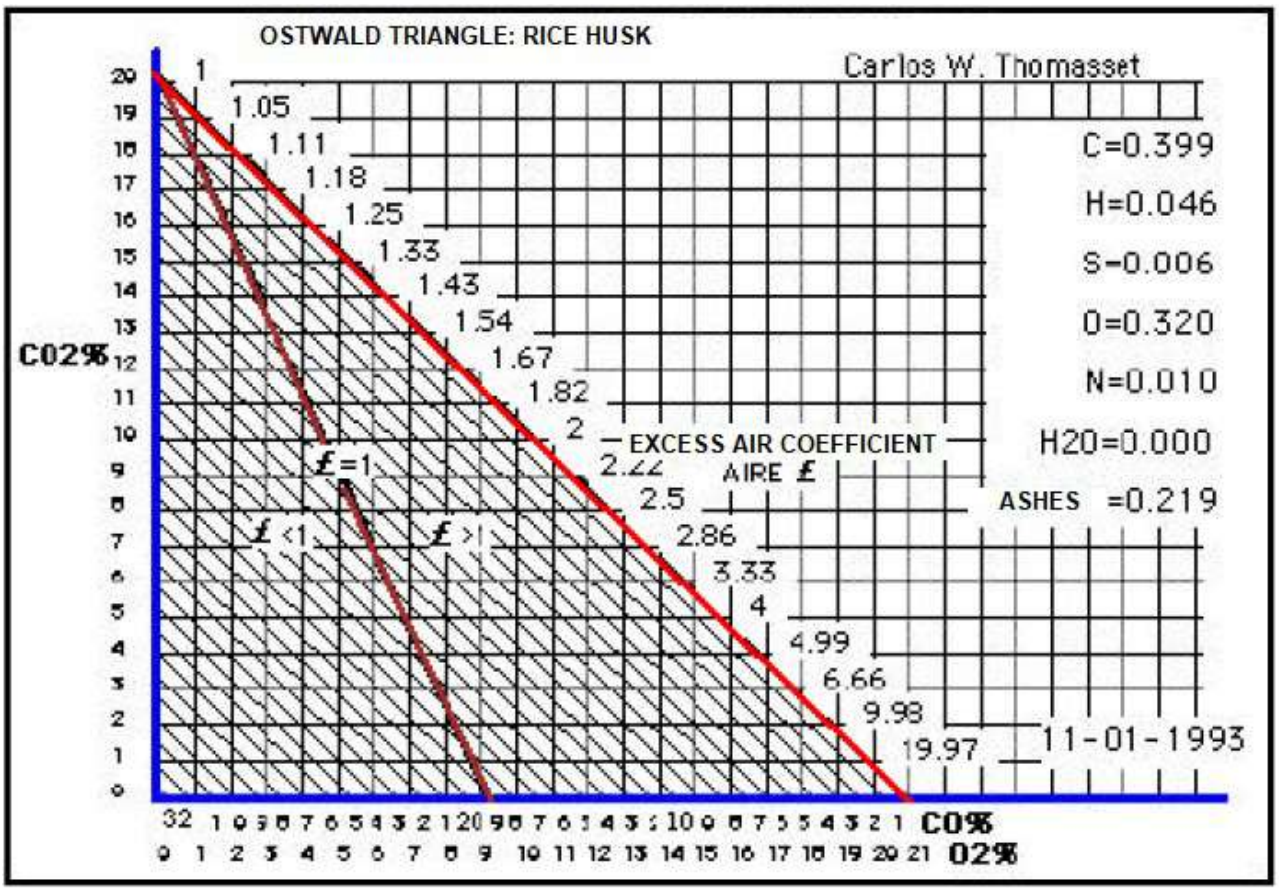
On one side is the shell loading inlet (a rotary or variable-thrust loader), which feeds an inclined grate made of cast iron plates. At the bottom, the grate consists of movable cast iron pieces (which advance the shell bed in a controlled manner, at which point it is almost ash).

At the end of the grate, there is a channel where the ash falls as the shell bed advances. Let's see how it works.

The husks are fed continuously (No. 1, according to the need to maintain a "blanket"). There is a first stage of drying the moisture from the husks with the heat of the hearth, and then, further above the hearth (No. 2) and forced by an air current that pushes the heat over the bed, this produces the release of organic gases from decomposition due to the heat (the high temperature of the hearth and a low-speed air current, which enters from below the bed, since the hearth is under negative pressure, sweeps and pushes these gases). These gases then combust (No. 4) with the remaining air and the tertiary air.

The "bed" descends as the combustion of the almost distilled "bed" continues (there is a final zone where only carbon and ash #3 remain), and after the combustion of the carbon (caused by the secondary air) only the ash will remain, this lower part of the bed being subjected to a mechanical movement that advances the bed, emptying the ash into an extraction channel.

Let's look at an OSTWALD triangle for rice husk.



In this Ostwald triangle for rice husks, we see that the maximum CO% is 32%, while in liquid fuels and natural gas it is lower. This is due to the presence of oxygen in the fuel itself.

The rice husks are considered to have already reacted with hydrogen, so what remains of the fuel is practically carbon (C). If we were to draw its Ostwald triangle, it would show a little more than 34% as CO% (carbon monoxide with pure carbon).

Combustion control must be carried out with instruments (measuring CO2% or O2% and CO%, the latter of which should be practically 0%, although this value is difficult to obtain if working with a low excess of air; this excess air is normally between 35% and 50%).

Otherwise, unburned gases appear, which have a very corrosive effect, especially due to the combination of the abrasiveness of the ash and the inherently corrosive sulfur, with other unburned gases of the acidic (pyroligneous) type.

As a practical control, the visible flame should not extend beyond one-third of the combustion chamber, thus ensuring complete combustion.

Flue gases must undergo a treatment process to remove entrained ash (otherwise, the area is contaminated with volatile silica).

A significant problem is the disposal of the ash (which is almost 90% silica). While it is used in some smelting furnaces, other uses are not yet applicable in Uruguay.

Rice husks are a fuel that should not be wasted, but unfortunately, as a residue, they are burned in the open air, and their energy value is not utilized. In Uruguay (as of 2011), only a couple of parboiled rice mills use them.

Some Portland cement kilns have used them, adding extra heat (and the resulting ash, to a certain extent, can be incorporated into the Portland cement mixture).

BURNING OF FOREST CHIPS AND WASTE IN GASIFIER BOILERS

The burning of forest chips and waste has increased in the last two years for use in boilers to generate electricity (either for direct sale or for use in cogeneration plants: generating electricity and process steam).

Wood chips and husks have been used in direct-fired boilers for many years.

Now, we are in a stage of using gasifiers (something that has not yet been adequately resolved in Uruguay; we are talking about 2009-10). Gasifiers have flat grates and are counter-current.

The wood chips enter from the top, the gases also exit from the top, and the primary air enters from below where the flat grate is located and where the ash is supposed to fall. In some cases, this is combined with the burning of sawdust blown into the torsional chambers themselves (which are attached to the gasifiers for secondary combustion).

A short-loose log gasifier, when gasifying, produces gases with temperatures ranging from approximately 450°C (842°F) to 700°C (1292°F). This causes tar cracking, preventing the formation of tar deposits that can cause fouling and combustion problems in the system (clogging gas valves, forming deposits that block the duct between the gasifier and the torsional chambers, etc.).

However, when burning wood chips and sawdust, the combustion tends to become incomplete within the gasifier, leading to the distillation of the wood (or biomass waste). This is evident in the low temperature of the gases exiting the gasifier, which generally rarely exceed 200°C (392°F).

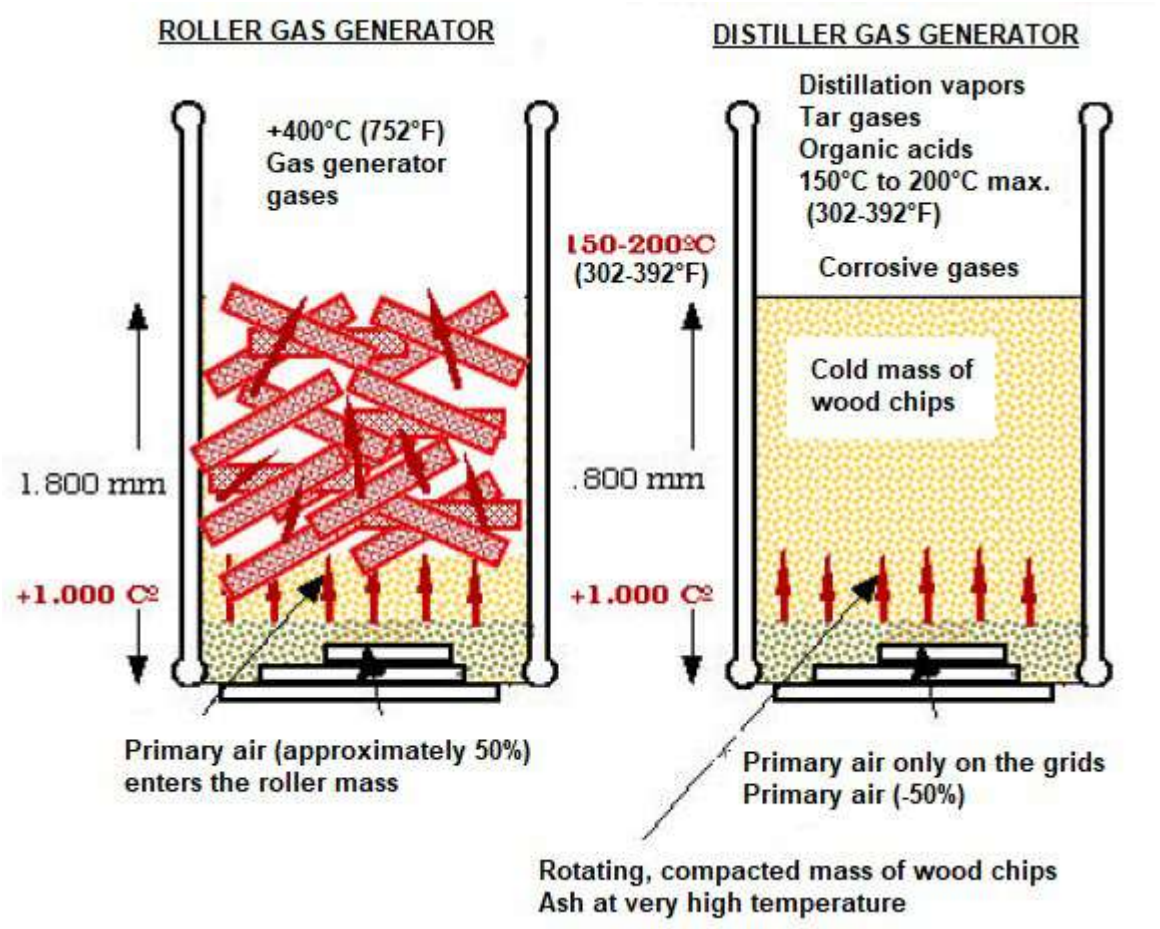
These "dirty" tar gases are composed of many distilled elements, some of which are very easy to burn, but pose a risk of explosion (organic gases of different composition). **When cold and containing tar, although difficult to burn when cold, they can easily explode due to their high flame speed (methane, alcohols, pyroligneous materials, etc.).**

When short logs are burned, although the operating procedure is the same, the falling logs do not "smother" the combustion. Primary air enters and heats up between the logs, reaching temperatures above 450°C (842°F). This causes the tar and other components to crack, forming other compounds that are more manageable for combustion control.

Gas-fueled boilers that burn logs rarely require liquid fuel burners as "pilots" to maintain the gas flame.

However, when burning wood chips and sawmill waste, it is unthinkable to operate at startup without a powerful burner to ignite and sustain the flame of the cooled gas from the distilled wood chips until the combustion chamber is properly heated.

We believe that this difficulty can be overcome by introducing primary air into the mass of chips, so as to produce greater combustion and thereby raise the temperature in the "mass" of chips and thereby cause a "cracking" of the organic molecules into gasifier gases and decrease the presence of tars and other heavy molecules.



ROLLERS STOCKS VERSUS CHIPS IN GAS GENERATORS

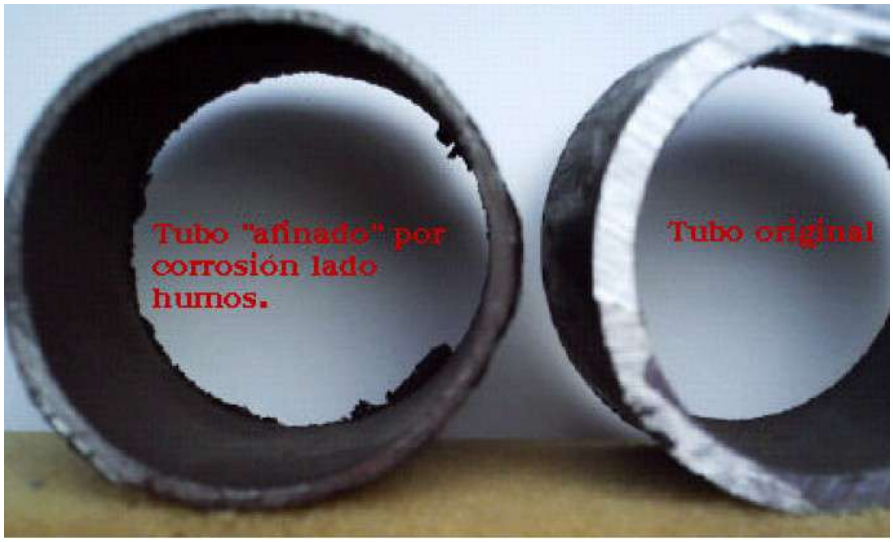
To avoid having to stop the gas generator when the "neck" of the connection between the gas generator and the torsional chamber becomes "blocked" (due to the accumulation of tar and solid materials, such as partially burned wood chips, etc.), the height of the chips is lowered (losing combustion capacity for gas generation) to raise the temperature to values that can burn these deposits.

Personally, I believe this is a problem if the temperature exceeds 750°C (1382°F), as it means the gasifier is vaporizing (its heat transfer increases because its exchange surfaces are exposed to a larger area and a higher temperature).

This high vaporization can cause the difficulty of steam removal to the boiler, reducing the cooling capacity of the water entering the gasifier. This is because the water's circulation depends on a very small difference in height for the "siphon" effect, and since 1 liter (dm^3) of water produces several liters (dm^3) of steam, the expulsion or removal of the steam with this increase in volume prevents the gasifier from operating flooded with water.

The upper part would operate flooded with steam, which absorbs little cooling heat from the gasifier's head tubes, causing high-temperature corrosion on the fire side. Added to this are the problems of expansion and contraction due to the disparate temperatures... metal can have.

Let's look at some tubes in the "head" of a gas generator that, due to exposure over time to such hot gases and also with the probability of attack by pyroligneous acids, the presence of CO (carbon monoxide) at high temperature attacks the metal.



LEFT: Corrosion-repaired flue pipe – RIGHT: Original (new) pipe

The formation of stones on the grill, a result of the high temperature of localized horizontal combustion, not only causes the wood to distill, producing tars and corrosive gases with a high risk of explosion,

but also results in the formation of "ash stones" from the ash that melts at a relatively low temperature (this situation can be improved by using magnesium oxide, which raises the ash's melting point).

A relatively inexpensive solution is the use of dolomite (ground into powder), which is composed of approximately 30% magnesium carbonate and 70% calcium carbonate. At high temperatures, both decompose into their respective oxides, raising the ash's melting point, as mentioned.

If these stones form, there comes a point where the gasifier must be stopped and removed; otherwise, the gasifier will cease to operate correctly (the rotating grate will jam, the air inlets will become blocked, and fuel capacity will be reduced).

It is also not advisable to operate the grate without a layer of ash, as this would expose it to high temperatures due to the "forge effect" produced by the air entering at high speed and impacting the burning material, raising the metal to very high temperatures and causing rapid corrosion.

Rotating plates at the bottom of the gasifier for ash removal and primary air intake.

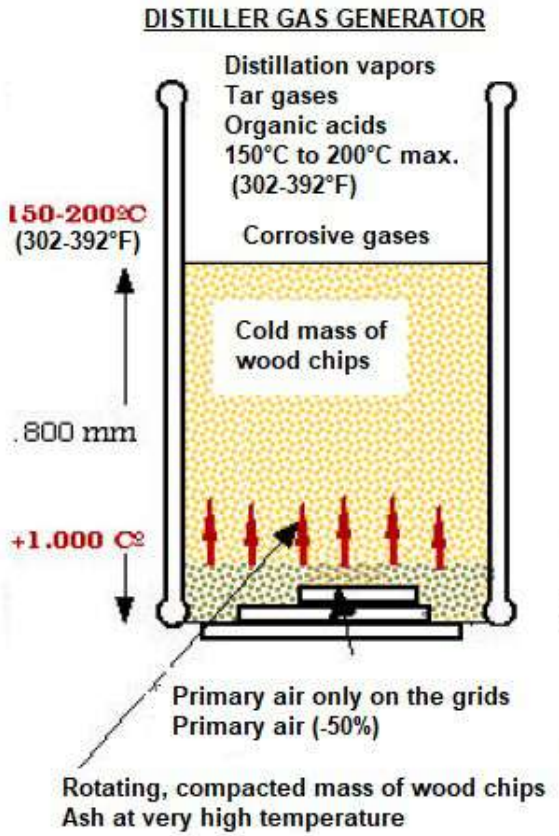
Wood chips become compacted due to poor combustion caused by excess air localized in channels.

This localized air raises the temperature, melting the ash and leaving other sections without air, which then fails to combust and becomes compacted.

The mass of chips tends to rotate on the rotating plates that form the chip support grid; this is one of the factors that allows the "clumping" of the chips (due to the lack of mobility between chips and the presence of tars). The air inlets between plates tend to become clogged, and the primary air is almost relegated to that which enters through the sides of the larger plate against the gas generator.

Perhaps this can be resolved by arranging refractory steel retaining elements to hold the rotating mass of chips, and these retaining elements should be angled to loosen them.

In reality, nothing has been done to remedy this situation so far, except to minimize the chip load. This improves the temperature of the gases formed (reaching almost 400°C/752°F), but complicates the handling of the gasifiers due to the small amount of residual fuel in combustion, requiring careful management to maintain the chip level.



las

Stones formed from ash,
due to the "forging effect" produced by the air.

The formation of chips wood tar is not only a problem of its complete combustion in the torsional chamber (especially if it is cold or if the biomass has a high moisture content), which causes poor secondary combustion that results in premature fouling of the boiler's heat exchange surfaces, but also causes corrosion in the hot and cold zones.

But the other problem with tar is the "clogging" of the safety guillotine valves for the isolation of the gas generators with the torsional chamber, guillotines that must respond quickly to a secondary flame failure problem, although this has been improved by putting high-power hydraulic pistons and also the injection of steam in the most problematic areas.

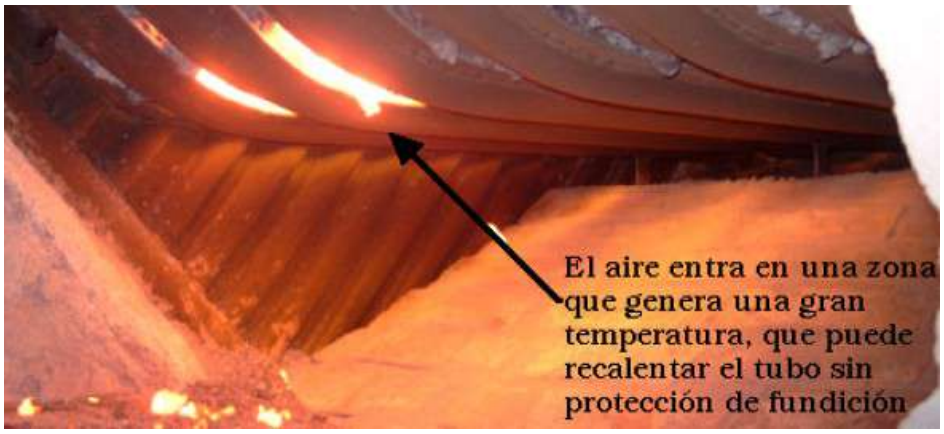
Wood tar is formed by the low temperature of the gases at the gasifier outlet.
It behaves like a wood still.

The formation **of "ash stones" is not exclusive to gas-fired boilers; it can also occur in direct-fired boilers** when the "forge effect" is **caused by a "poor grate design"** (such as grates formed only by the tubes).

It's important to remember that grates are not only for supporting the burning logs, but also for ensuring proper air distribution in contact with the burning wood.

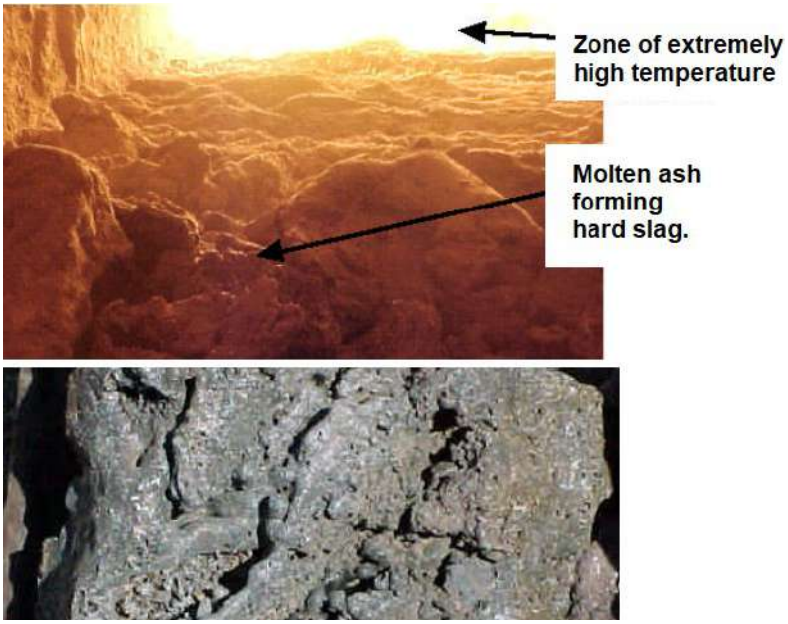
This prevents areas where air doesn't flow evenly and areas where air enters only in specific spots, causing the "forge effect"—that is, a flame of extremely high temperature, as if it were in a forge.

Let's look at a photo.



The air enters an area that generates a high temperature,
which can overheat the tube without cast protection.

Stone formation in direct-fired boilers is not only due to the "forge effect," but can also occur if very low moisture content fuel is used (pellets with less than 10% moisture). Let's look at this:

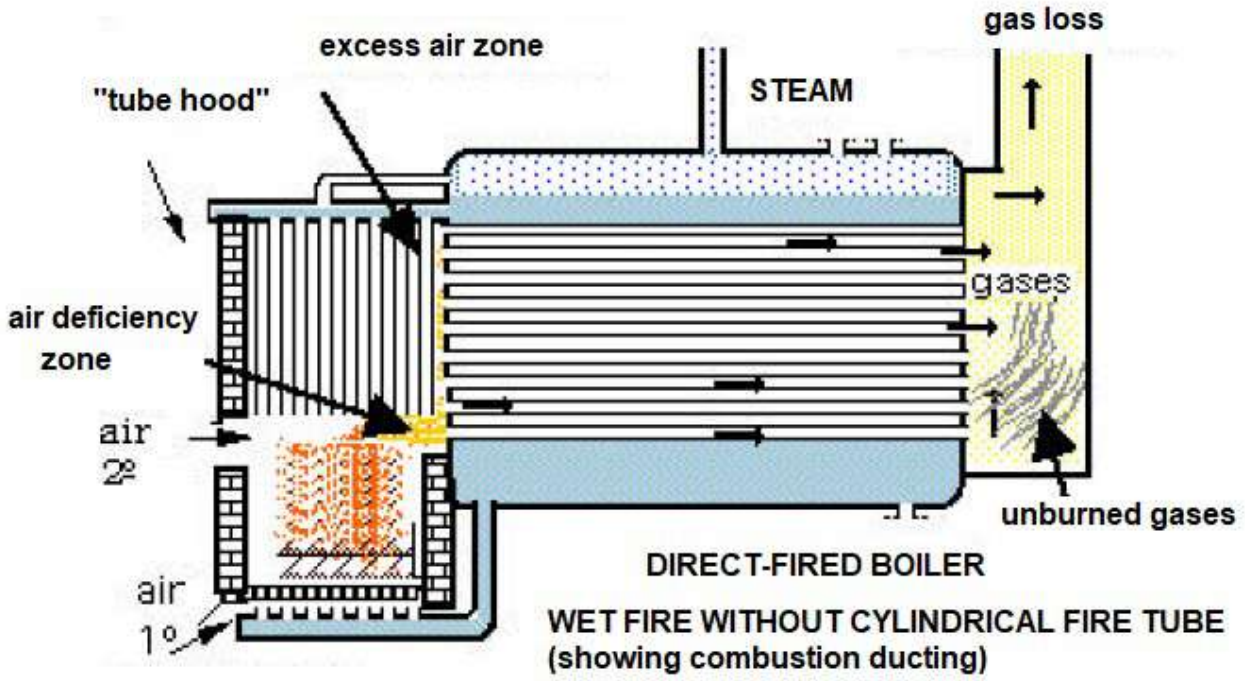


Photographs of "molten" ash forming a hard slag, and of dragged ash blocking the steam blower of the convective bank within a few hours of operation.

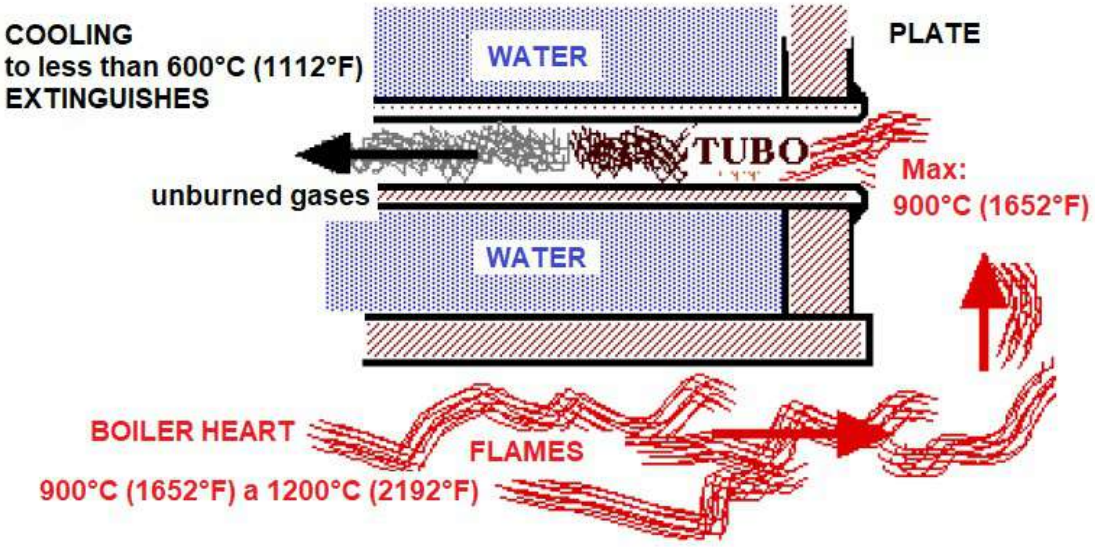
The major problem with burning such dry pellets on an unsuitable grate is that it can lead to the destruction of the moving grates, since the resulting stone has the hardness of lava (molten rock), which obstructs their movement.

There may even be volatiles from this molten lava that are deposited on the boiler tubes as they are carried by the gases and condense on the relatively cool surfaces of the tubes.

PROBLEMS IN FIRE-TUBE BOILERS WITHOUT A FIRE TUBE



Another problem with "direct combustion" is when the boiler is designed without a combustion tube, because if complete combustion does not occur before the combustion gases enter the tubes, these incomplete flames are extinguished upon entering the tubes and quickly foul them (producing a "tube" of ash that restricts the passage of gases, which increases the problem of poor combustion and the fouling process, resulting in a significant loss of energy as "unburned gases").



There is a "belief" that the cast iron grates that go over the cooling tubes of the grate in direct-burning chimneys are to "hold the logs" (rolls), and this is not actually the case.

The cast iron grates have such a shape and distribution that their primary function is to distribute the "primary" or "under-grate" air so that the air is correctly distributed among the burning biomass.

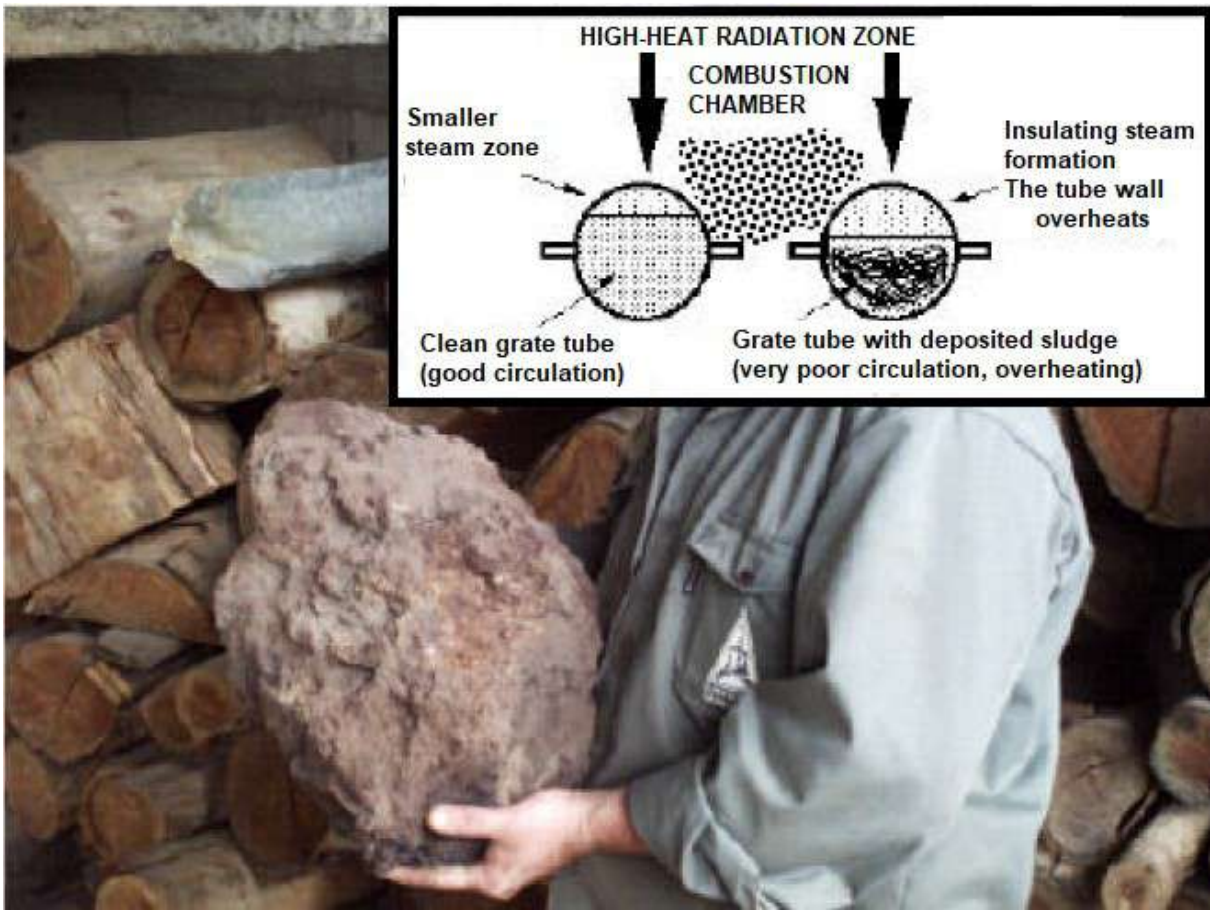
When these "cast iron grates" are replaced by the simple support offered by pipes spaced apart, the airflow becomes uneven.

In some areas, the pipes, resembling a funnel, block the passage, trapping ash and preventing airflow. In other areas, excessive air enters, creating a "forge effect" (excessive air leading to high temperatures and the formation of "ash stones").

Let's look at a "ash block" formed by the previous boiler, which lacks a primary air distribution grid.

It only has combustion support tubes through which boiler water circulates. However, this allows the "forge effect" to easily develop as part of the area between the tubes becomes blocked by the conical shape formed between two tubes.

Meanwhile, in other areas, the combustion blanket remains "perforated" by the primary air impacting it like a forge (producing a high temperature that melts the ash, as shown in the following photo).


HIGH-HEAT RADIATION ZONE
COMBUSTION CHAMBER
Smaller steam zone
Insulating steam formation
The tube wall overheats
Clean grate tube (good circulation)
Grate tube with deposited sludge (very poor circulation, overheating)

The grate becomes "covered" after a few days, and significant ash accumulations form due to the high temperature developed in the perforated area of the covered grate. There is a risk of tube overheating.

The formation of "ash stone" is not exclusive to the burning of very dry biomass; it can also occur depending on the origin of the biomass (for example, eucalyptus and pine forests near the sea have a high salt and sand content, with the sand clinging to the bark, especially in pines).

However, they can also be the source of the biomass, as is the case with firewood from natural forests (hardwood, very old, with a very high salt content).

Although burning firewood from natural forests is expressly prohibited to conserve them, it is no longer advisable to use it in a boiler, since the resulting ash stone has the hardness of glass (a very hard lava); it cannot be broken with a crowbar, the boiler must be stopped, and the grates must be cleaned by hammering, which is not recommended.

DESIGN AND ADAPTATION PROBLEMS OF WOOD-FIRED BOILERS

The design and adaptation of wood-fired boilers requires extensive experience in handling wood-fired boilers.

While it's generally thought that wood-burning boiler problems are solely related to combustion, this isn't the case. Wood (or biomass) boilers typically require combustion chambers attached to new or existing boilers, whether they are direct-fired or gas-fired.

The most common mistake is a lack of understanding of the internal water circulation system, whose function is not only to supply water for steam production but also to cool the heat transfer surfaces.

Remember that at the same pressure (saturated steam temperature), the volume occupied by a mass of water is much smaller than the volume that mass of water would occupy once transformed into steam (the lower the boiler's operating pressure, the greater this difference).

For example, if the boiler operates at 10 kg/cm² (142 PSI), the volume of 1 liter (1 dm³) of water, upon evaporation, transforms into 180 liters of steam (180 dm³). If the boiler operates at 50 kg/cm² (711 PSI), 1 liter (1 dm³) of water, upon evaporation, transforms into 39 liters (39 dm³) of steam.

But let's remember that water is much better at cooling heat exchange surfaces than steam (which behaves more like a gas than a liquid). The steam bubbles that form in saturated water absorb a large amount of heat (due to the latent heat of vaporization), but it is the presence of water alongside the steam bubbles that "wets" the surface and improves the heat transfer coefficient, and it is the steam that forms where that large amount of heat goes.

The problem is that if we "put" a volume of water into a direct-burn combustion chamber or a gas generator (or torsional chamber), we must remove a quantity of water and steam with a much larger volume due to the formation of said steam.

This is done by means of the "evaporator" tubes (or "ventilation" tubes, or return tubes to the boiler at the top of the combustion chambers).

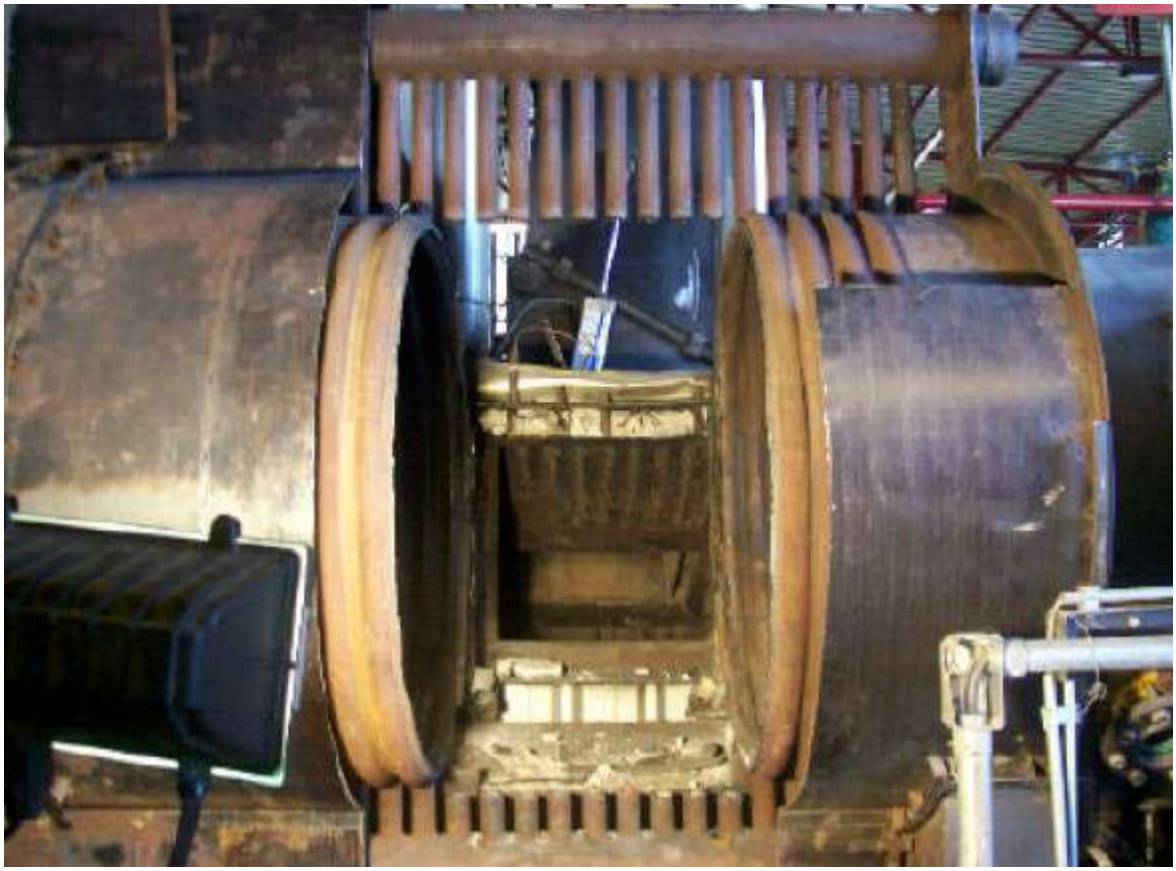
The problem arises when the return tubes ("evaporators") are insufficient at high combustion rates to extract all the evaporated water.

The resulting flow creates a pressure drop (like a steam plug) that prevents enough water from entering to cool the tubes in the drums or gasifiers (or torsional chambers).

And since steam has a lower capacity to absorb heat, it causes the tube walls to overheat, leading to wear from high-temperature corrosion or even burning.

This problem is exacerbated by water conditions (high pH, high salinity, contaminants that alter the water's surface activity, such as grease, oil, etc.) or if the surfaces to be cooled have any scale buildup.

This problem can be identified through two observations or measurements. The first is the fluctuation of water levels, and the second is placing a surface thermometer to measure the temperature of the return tubes (or steam tubes) to the boiler.



TORSIONAL GAS GENERATOR CHAMBER WITH CIRCULATION FAILURE

Add approximately 15°C to 20°C (68°F) to account for heat loss from the tube wall. Observe whether this temperature is above that of saturated steam, indicating "superheated" steam.

This means that the upper part of the combustion chamber tubes is cooled only by steam, which raises the tube wall temperature, causing wear due to high-temperature corrosion.

In some cases, the return tubes release bursts of water and steam, causing water carryover into the boiler steam. This occurs because the discharge impacts the boiler's water separators, which are generally insufficient to separate the water and steam under these conditions.

Wood-burning boiler conversions are the most dangerous if the internal circulation, or cooling of the heat exchange surfaces, is not respected.

The case we will show below didn't even reach the working pressure, and the boiler's combustion chamber "collapsed" due to lack of cooling.

While it wouldn't pass inspection from a structural standpoint, it at least withstood the hydraulic test pressure. **However, in the first attempt to build steam pressure through combustion, it collapsed before reaching the working pressure (7 kg/cm², 99 PSI), causing an expansion that propelled the boiler's front 85 meters. The people who were starting the boiler were seriously injured.** Let's look at the photo.

In the case above, if we look at the water inlet from the boiler to the combustion chamber, which is a water collector of no less than 4 inches, the discharge at the top consists of three 1-inch "boiler" tubes.

If we consider that when 1 liter (1 dm³) of water flows down, it evaporates into 277 liters (dm³) of steam at 6 kg/cm², displacing the water from the adapted combustion chamber into the boiler body, the pressure at which the boiler

furnace opened like a "sardine can," causing a very violent expansion that nearly resulted in the deaths of several people, in addition to material damage that is insignificant compared to the loss of human life.

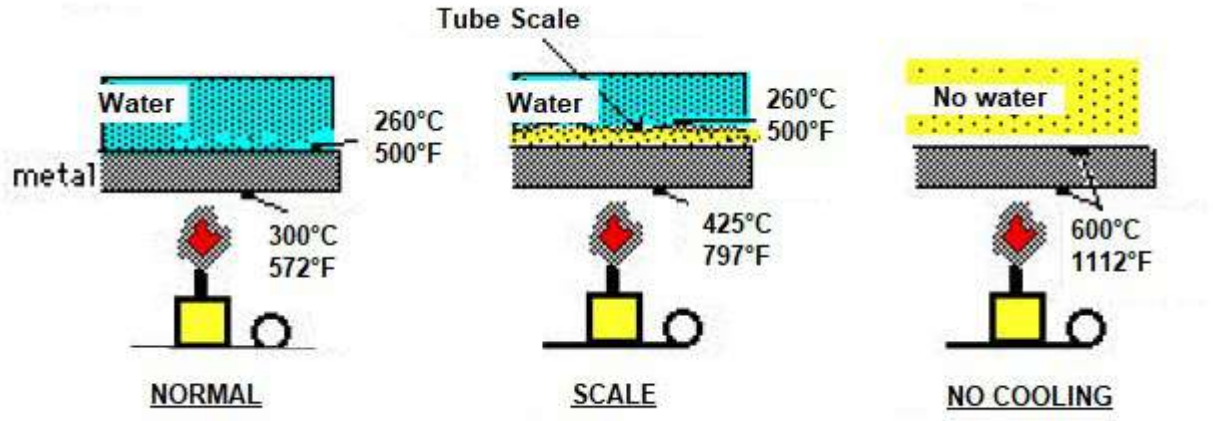
The risk of "adaptations" is greater because they generally involve people who do not have sufficient knowledge of the subject and what can happen; it is not just about putting water in but about how to remove that partially evaporated water and that if it has no outlet the steam "pushes" the water making it back towards the boiler, which makes the furnace work without cooling water.

EXPLOSION OF A HOMO-TUBULAR RECOVERY BOILER

CHAPTER 6: EMERGENCIES

The boiler is an element subjected to internal pressure: this pressure subjects the metal "walls" of the boiler to very high stresses (the force on the walls is equal to the surface area times the pressure in coherent units, that is: kg/cm² x cm² = kg or lb/in² x in² = pounds, and this stress will depend on the geometric shape and thickness of the material).

Therefore, we must keep in mind that the stress in the material in a low-pressure or high-pressure boiler is the same, since its thickness will be proportional to the pressure and dimensions. This means that there are no safe boilers; all are boilers and must be treated as such, due to the risk of explosion.



Temperature at which the metal of the boilers can be found under normal conditions or in case of alterations.

But let's consider that this metal is also subjected to high temperatures (very high on the fire side and lower on the water or steam side).

However, if there are deposits on the water side, i.e., scale or sludge, the poor heat transfer from the "fire" to the water and steam means the metal wall doesn't cool down quickly enough, and the metal temperature can become very high, to the point of softening and stretching under the pressure, or simply "burning."

And it is also subject to temperature variations (as combustion conditions and pressure on the water side change, in addition to the possible—and not advisable—feeding with cold water, the metal will be subjected to a "bellows-like expansion and contraction" similar to that of a bandoneon, which fatigues the metal, like "cutting a wire by repeatedly bending it").

These physical variations in the metal, among other things in fire-tube boilers, can cause the tubes to loosen on the mandrels in the plates and cracks in the plates themselves, causing leaks and a possible accident.

This variation in boiler dimensions, due to temperature changes—more than 1.2 mm per meter for every 100°C (212°F) variation—necessitates that the boiler have a support system at its base, the floor that supports it, to allow for expansion and contraction. Otherwise, in a boiler, this can cause stress corrosion in the casing or dome.

Over time, this can lead to an accident, since the casing can be perforated at the joint between the support leg and the casing itself—a very serious accident if it occurs.

These elements that facilitate expansion and contraction, generally at the base of the boiler (legs), must be kept free and lubricated if necessary to prevent them from seizing up.

Example:
A boiler with a distance of 5,000 mm (5 m) between its front and rear legs, and operating at 10 kg/cm² (142 PSI), with a temperature of 183°C (361°F) at the boiler body, has a thermal expansion difference between the casing (between the legs) and the support base of:

(183°C - 25°C) / 100°C x 1.2 mm x 5 m = 9.48 mm

This 9.48 mm (nine and a half millimeters) difference must be absorbed by the expansion system between the boiler's initial temperature (cold) and its operating temperature (183°C, 361°F).

To the above, we must add the fact that heat transfer to water, even when the surface on the water or steam side is clean, depends on the velocity of the water or steam over that surface (for example, if we want to cool food in a container more quickly with water, we agitate the water surrounding the container and stir the food).

In the boilers we are considering, water circulation depends on its "natural circulation" (in Uruguay, most boilers use natural circulation, although there may be boilers with forced circulation using pumps, such as the large ANCAP boilers, and smaller coil boilers in industry).

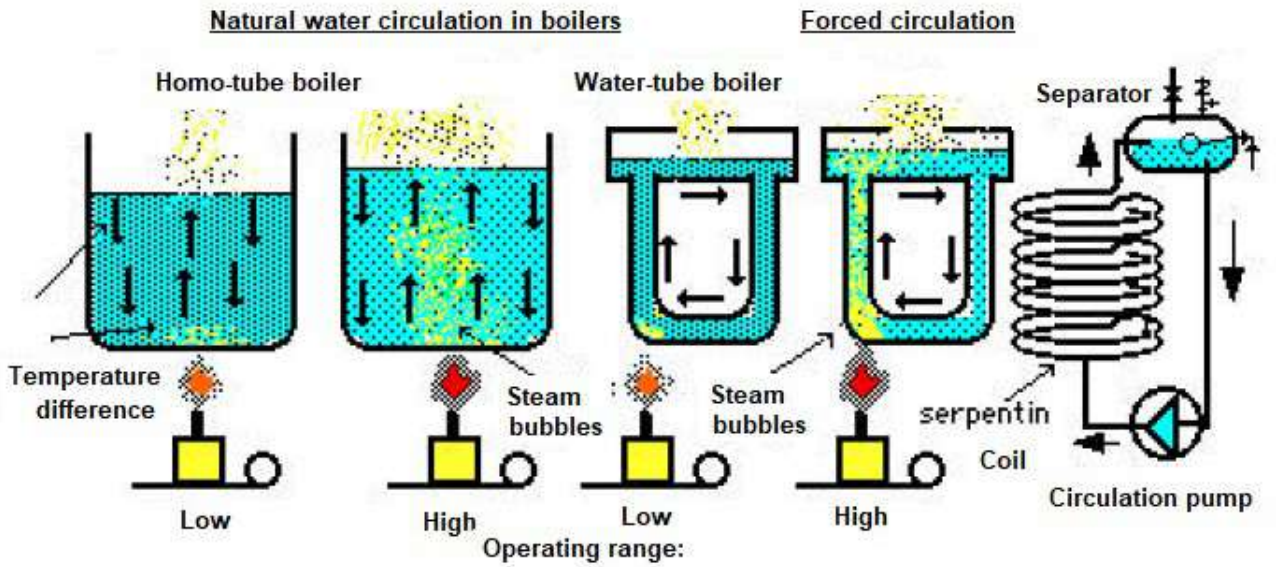
This natural circulation is caused by two factors: the difference in density (weight per unit volume) between the hotter water (which is lighter and rises) and the colder water (which is heavier and sinks), and the formation of steam bubbles inside the water (against the heating surfaces).

These bubbles, being lighter than the water, rise and contribute to the water circulation (this can be observed in a container of boiling water).

Both causes of circulation are carefully studied during boiler design. While these circulations can be intense, they are easily disrupted, potentially leading to insufficient cooling and overheating of the boiler material.

This can cause fatigue (cracks), deformation, or burning (combustion with oxygen from the air or from the decomposition of water or steam).

This leads us to consider that the internal circulation of boiler water (and steam in superheaters) are fundamental factors for the design and maintenance of the operation and integrity of a boiler.



This failure of the "natural" water circulation inside the boiler can be caused by several reasons.

These include: excessive combustion, a very steep drop in pressure with the fire at maximum, a pressure drop that is too rapid (opening a large steam valve), and combustion occurring outside the designated area.

Due to wall breakage or poor control, local fouling from soot accumulation, etc.), blockages from sludge or scale buildup, tools left behind during repairs, or detached elements inside the boiler (plates, scale fragments, etc.).

Improper purge (the sludge collectors on the walls of water-tube boilers should not be purged when they are operating at a high rate of vaporization; the same applies to "caps" and gas generators),

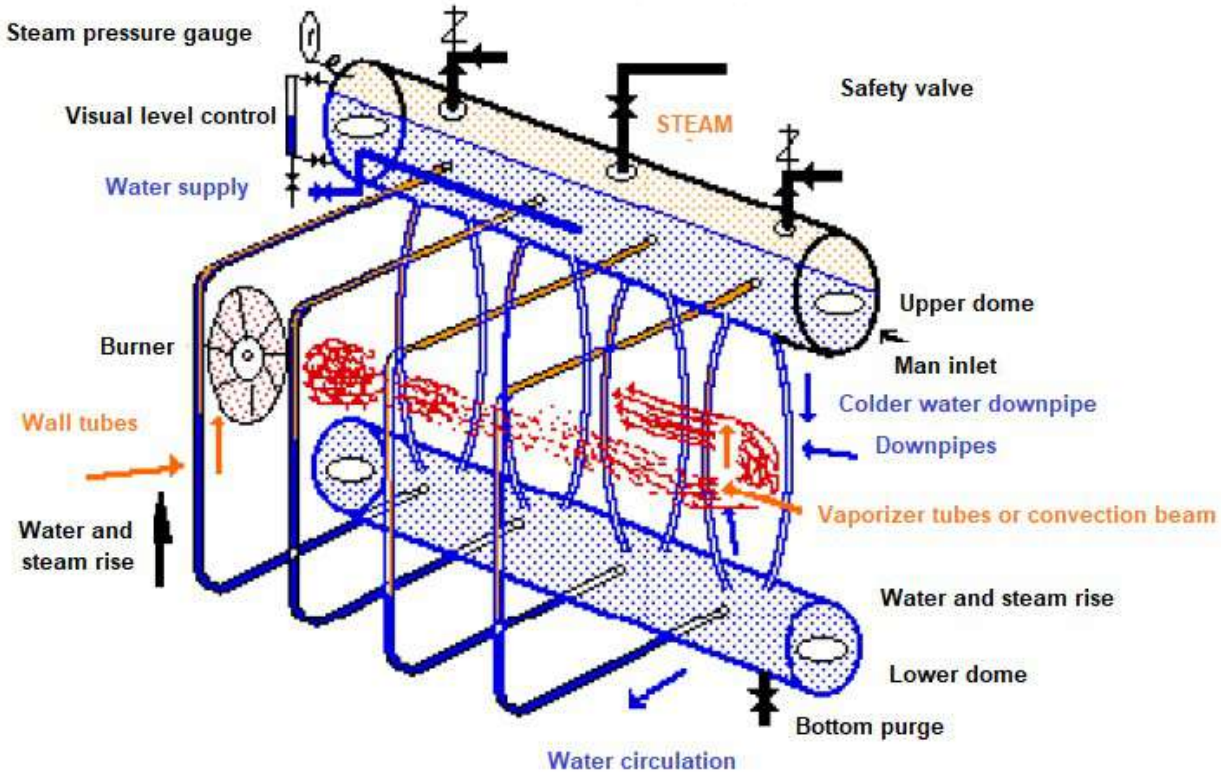
or due to a lack of chemical controls (very high levels of dissolved and/or suspended solids, very high alkalinity: high pH, contamination with organic elements, or improperly performed treatments: excessive dosing), etc.

In forced circulation, combustion is "locked" (dependent) on the pump operating or by means of a flow sensor (circulation flow detector), so that combustion ceases immediately when the water circulation stops.

Otherwise, the coil, lacking water circulation, would burn out.

As we can see, the boiler is a dynamic, complex element, and we must be attentive to sudden problems that may arise, which we will call "Emergencies."

To deal with these "Emergencies," we must be informed about how and why a boiler works, since, given the circumstances of an emergency, we won't have much time to think. This means the need for mental training for every situation that may arise.



Since "low water level" is the most significant cause of boiler accidents, we must pay close attention to this problem:

1.- Symptom: Low boiler pressure.

When boiler pressure drops, it is usually because the amount of combustion is insufficient to achieve the necessary vaporization.

But: be careful! Do not increase combustion before visually checking the water level: as it could also be due to insufficient water inside the boiler (if the water supply fails and the level control system—which shuts off the burner and sounds the alarm—is blocked, usually by sludge or scale, we risk making the mistake of increasing combustion manually or automatically).

This is the number one cause of serious boiler accidents.

The explanation is that when the water level drops, the heating surface that vaporizes the water is also exposed.

With the reduced heat transfer, less vaporization occurs, which is insufficient to maintain pressure (this is particularly serious in fully automatic burners, as combustion is regulated by pressure and should automatically shut off if the burner is functioning correctly).

In the case of the stoker, he is also guided by the pressure (although there may be a level control with burner cutoff and/or alarm, there is the alternative that if the stoker is attentive he will always check the water level as a primary control before increasing combustion).

Conclusion: Never increase combustion without first checking the water level, or if the pressure drops, check the water level immediately.

If the water level has dropped, first reduce combustion or turn off the burner, then quickly bleed the system to determine if the level is high or low (if the level is high, the water level will reappear when you bleed it; if the level is low, it will not reappear when you bleed it).

If the water level is low or has disappeared, immediately turn off the burner, shut off the water supply, and close the steam valve.

This will prevent the boiler from running completely dry. Without combustion, no more steam will be generated, and if overpressure occurs due to the heat of the material, the safety valves will activate.

However, if we completely empty the boiler, it will overheat locally and its components will warp. A safety valve or another steam valve can be opened to slightly relieve the internal steam pressure.

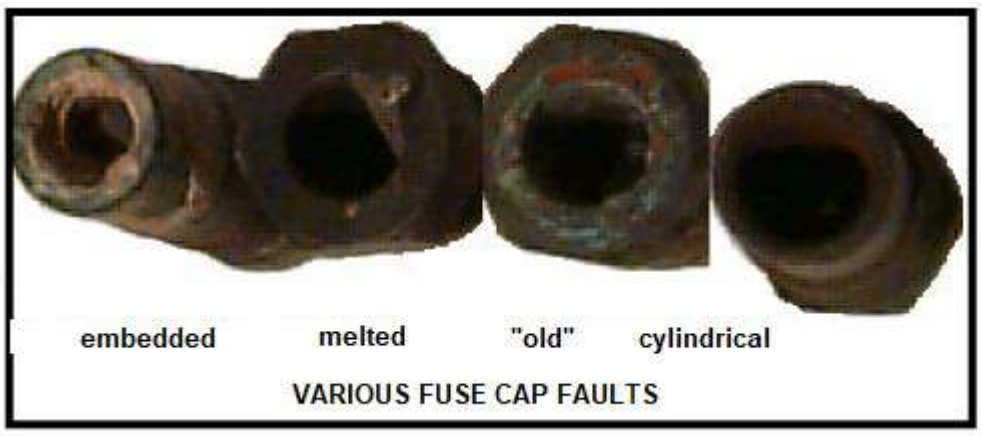
Almost completely close the air intake (leaving a small draft to maintain a gentle flow of gases in the combustion chamber, but this should be very small to avoid stress or combustion of the overheated metal).

If the boiler burns cellulosic materials (wood, husks, etc.), completely close the air intake so that no combustion occurs.

Do not add water if the water level is outside the visual level or below the lowest level test tap. Adding water to the boiler, which is relatively cold compared to the superheated metal, can cause damage ranging from warping to rupture of the material this can lead to a boiler explosion (due to internal pressure and material failure, although a true boiler explosion usually occurs when the boiler is completely empty and the metal is red-hot).

In the case of adding water, a true explosion or reaction occurs between the water and the superheated metal, producing a violent expansion due to the physicochemical reaction between the iron of the boiler and the oxygen-hydrogen in the water.

In this situation, the boiler should be allowed to cool to room temperature (with the burner off, water supply shut off, and steam shut off). Once cool, the entire boiler should be inspected, including the fusible plug (which should melt if the water level has dropped below it).

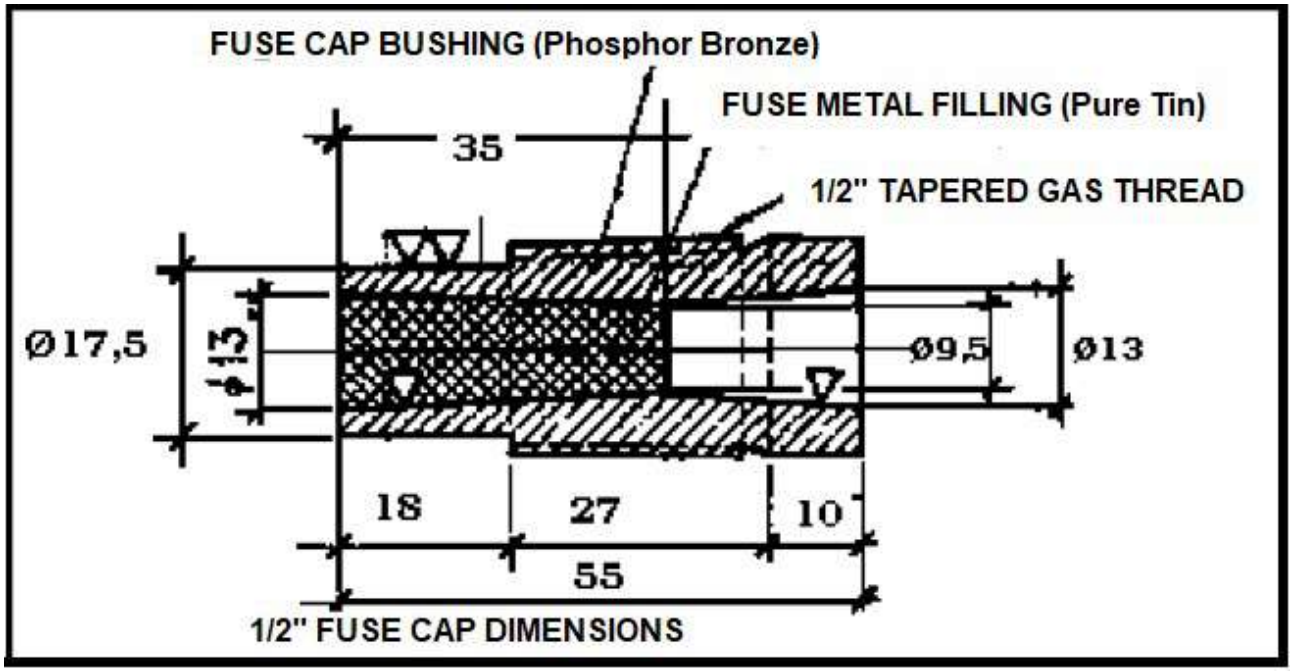


VARIOUS FUSE CAP FAULTS

If any overheated parts are observed (discoloration, deformation, loosening of tubes, etc.), a technician should be called for a more thorough inspection.

In any case, it is advisable to perform a hydraulic test before returning to service, after the visual inspection.

The fusible plug will not always melt, since if it is embedded, it may melt but not escape "vapor" because it is blocked by the encrustation (hence the importance of replacing fusible plugs at the expected times, between 6 months to a maximum of one year).

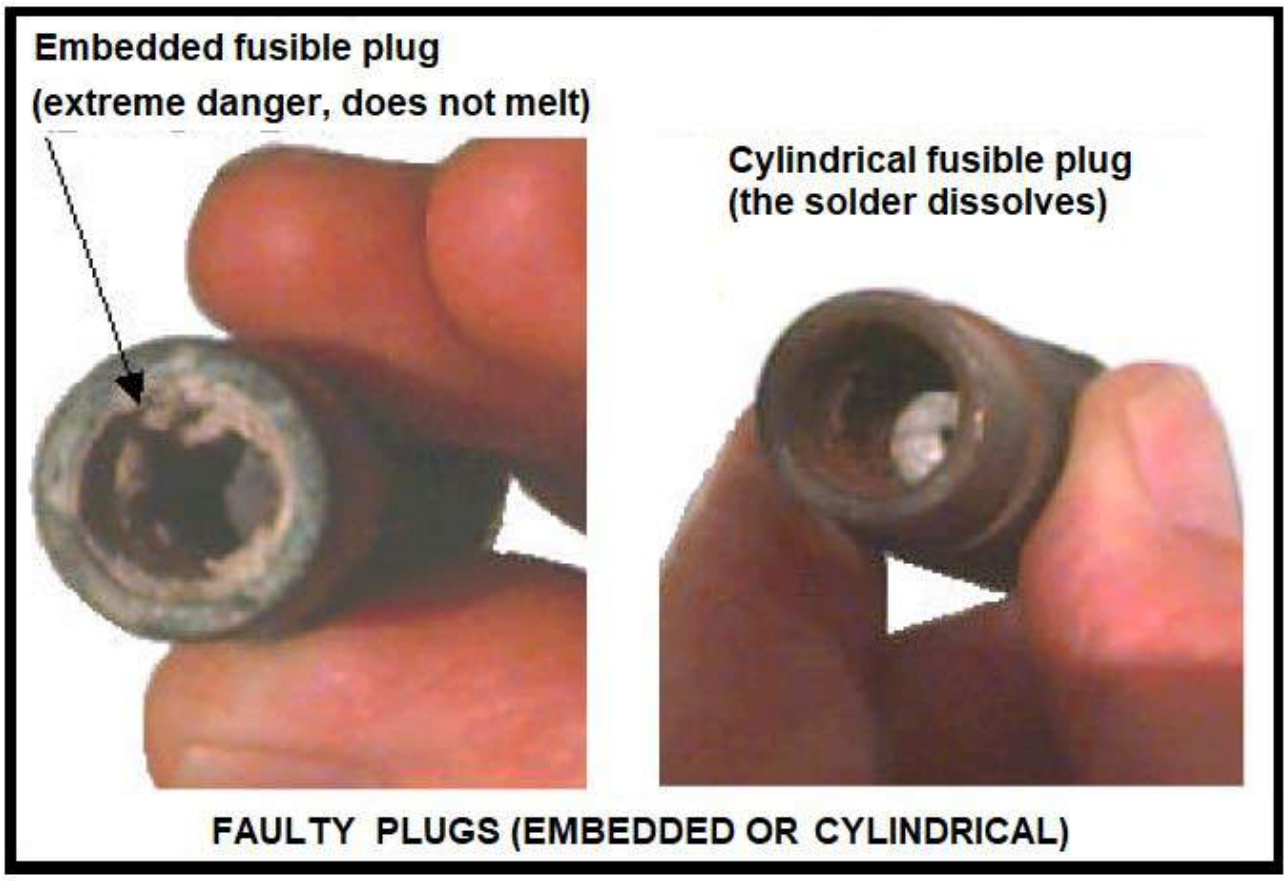


Generally, we can't say that a fusible plug can extinguish the boiler fire (the original reason for its invention, as well as release pressure), but its presence is very useful, since it indicates an anomaly (low water level or repeated, albeit subtle, low levels).

This gives the boiler operator a warning to take action, or the technician a telltale sign that can confirm a situation of doubt (whether there was a low water level or a physicochemical stress-activation problem in the water that altered the internal circulation, causing localized overheating that leads to material failure).

Also, if a fusible plug partially or completely melts, it's not necessarily due to a low water level. It could be that the fusible plug wasn't manufactured according to strict standards, meaning issues with dimensions (tapering is very important; if the plug is cylindrical in the part where the tin is located, it's

very likely to leak in a short time), tin quality (purity), or the casting process. (cleaning, temperatures, etc.)



INADEQUATE FUSE CAPS
Embedded fusible cap (high danger, does not "melt")
Cylindrical fusible cap (the tin dissolves)

In the event of a water level drop due to a "high level," with the fire extinguished or at minimum, the water level should be lowered quickly (by temporarily shutting off the supply and preferably purging from the surface: continuous purging).

The risk in this case is water carryover, which can cause a "water hammer" (water propelled at the speed of the steam, which, upon stopping, causes a "hammering" against the pipes or equipment) in the pipes or equipment where steam is used (this can be very dangerous in equipment such as dryer cylinders, kettles, etc.).

Also:
A high level can be caused momentarily by very high steam consumption (generally with a high vaporization rate or with very high water chemical limits).

In this case, it is advisable to slightly reduce the steam output to alleviate the excessive consumption.

Otherwise, if we purge the system, we can go from a high level to a low level once the peak consumption has passed.

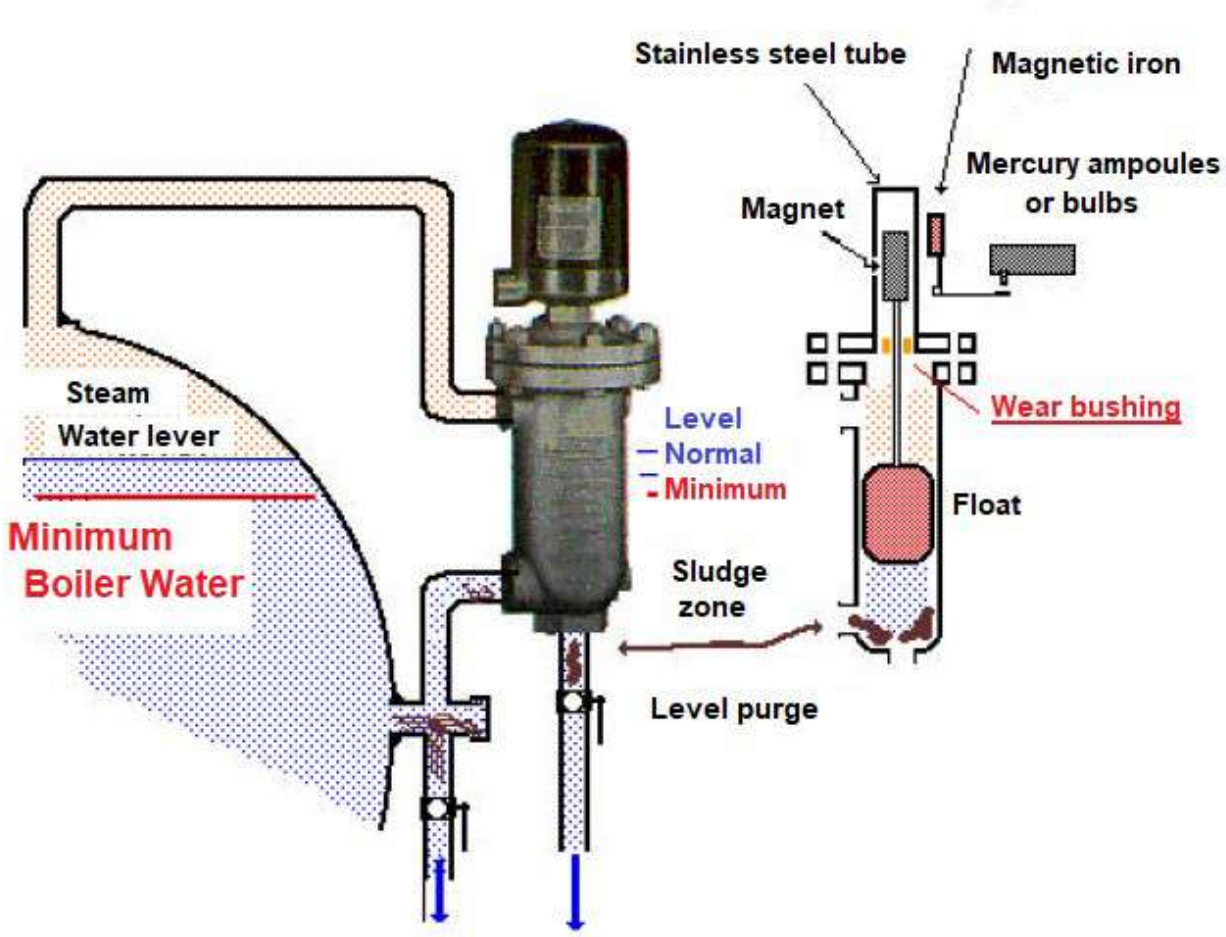
In float-based level control systems (McDonnell® and others), an excess level (or high level) can be caused in part by a "puncture" (a perforation of the float, which fills with water and loses buoyancy). This perforation is generally caused by corrosion (especially in stainless steel floats, which are attacked by chloride ions in well water or when salt from the softener enters the boiler, or by a lack of blowdown).

Or there may be a partial (or total) "collapse" caused in the float by being at the maximum pressure limit it can withstand. This can be caused by various reasons: a hydraulic test, a "water hammer" during purging, or the piping and valve system is inadequate, causing an excess of steam flow that strikes the float and begins to "crush," preventing it from withstanding the pressure as it loses its spherical shape.

Therefore, it should be purged as much as possible, slowly until fully open, which should not be an excessive amount, but (either because the boiler pressure has been high and the float is at the limit of the working pressure, or sometimes caused by a hydraulic test that exceeds the maximum pressure that the float can withstand**). In this case, the high level remains permanently and the solution is to change the float.**

When a buoy has a puncture, do not attempt to weld it; it is very dangerous (since the buoy contains water, and when heated for welding, the water vaporizes and creates high internal pressures that can cause the buoy to burst; serious accidents have occurred when attempting this type of repair).

Replace the buoy with a new one, but then investigate the cause of the failure.



In some float-type level gauges, where the float moves along a guide inside a bushing (as with Magnetrol® gauges), **the failure can occur either due to a problem with the float itself or a problem with the rod's movement within the guide bushing (which tends to jam).**

This is very dangerous because it can jam at a high level (causing a low level by preventing the boiler from being fed and eliminating the low-level cutoff, which is very dangerous) or at a low level (causing a high level and thus dangerous water carryover into the steam).

Water level failures are not only caused by mechanical component failures (such as in the float or its movement, or in the components associated with the buoy, including its lever or displacement mechanism), but also by the system that transmits the buoy's position to the electrical sensors. These sensors, which may have been mercury bulbs (which should no longer be used because mercury is a pollutant), are now replaced by micro-switches. These are moved, under low pressure, by levers through a bellows, which allows movement but prevents steam from escaping.

This stainless steel or copper bellows can also be punctured or fatigued—causing it to crack—for the same reasons as the float: excess chloride ions (in the case of stainless steel) or ammonia (in the case of copper), or excessive pressure during hydraulic testing. This can cause the system to become flooded with steam, and the resulting humidity can further damage the system. "short circuits" that cause the indication of the mercury bulbs or the micro-bulbs to be false, potentially leaving the burner without low-level cut-off protection).

When the pressure is higher, in McDonnell® controls (or other float systems), instead of transmitting the float's movement via a "seal" element (a stainless steel or copper bellows), the linear displacement of a magnetic element inside a "non-magnetic" tube (copper or stainless steel) is used. This displacement is detected by small magnets that are attracted to an opposing spring as the magnetic element passes. These small magnets are connected to micro-switches, which open and close according to the water level.

The most common failure of these components, while it can be mechanical (float, displacement, mud, etc.), is that the micro-switches themselves can fail, or the mechanical system of the micro-switches can become fatigued and fail. Therefore, the following recommendations should be considered:

All level controls should be replaced every few years (as indicated by the manufacturer), but what cannot be done is to purge them improperly, since the lack of purging or poor purging practice (purging into "air" or "timid" purges) does not clean the internal part of the control, allowing the floats to "hang" on the deposited sludge, causing the boiler to run out of water and not shut off due to low level, which is very dangerous.

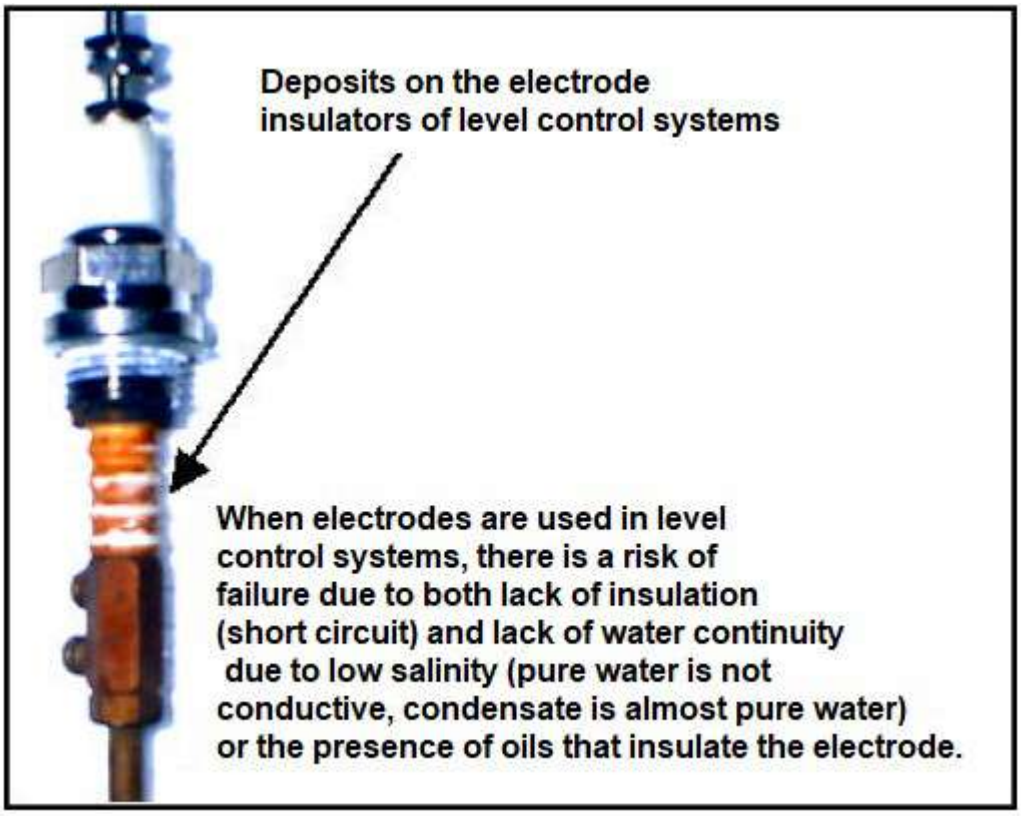
For all these reasons, **there should be at least two level controls (with burner shut-off in case of low level), the levels should be purged every four hours, and the burner should be checked to ensure it shuts off**.

Electrical cables should be replaced every five years (or as needed, using cables appropriate for the operating conditions, temperature, mechanical protection, and humidity).

It is often advisable **for each level control to have its signal drawn through separate electrical conduits to prevent a steam leak from a bellows from potentially short-circuiting the entire system**, as steam can travel through the protective conduit of the cables to the control panel itself

and cause a major short circuit.

There is a current trend towards using electrode-based level controls (this is because they are less expensive than float controls). Companies like McDonnell® recommend that the level control heads and their electrodes be replaced every two years (this is due to the problem explained below).


Deposits on the electrode
insulators of level control systems
When electrodes are used in level
control systems, there is a risk of
failure due to both lack of insulation
(short circuit) and lack of water continuity
due to low salinity (pure water is not
conductive, condensate is almost pure water)
or the presence of oils that insulate the electrode.

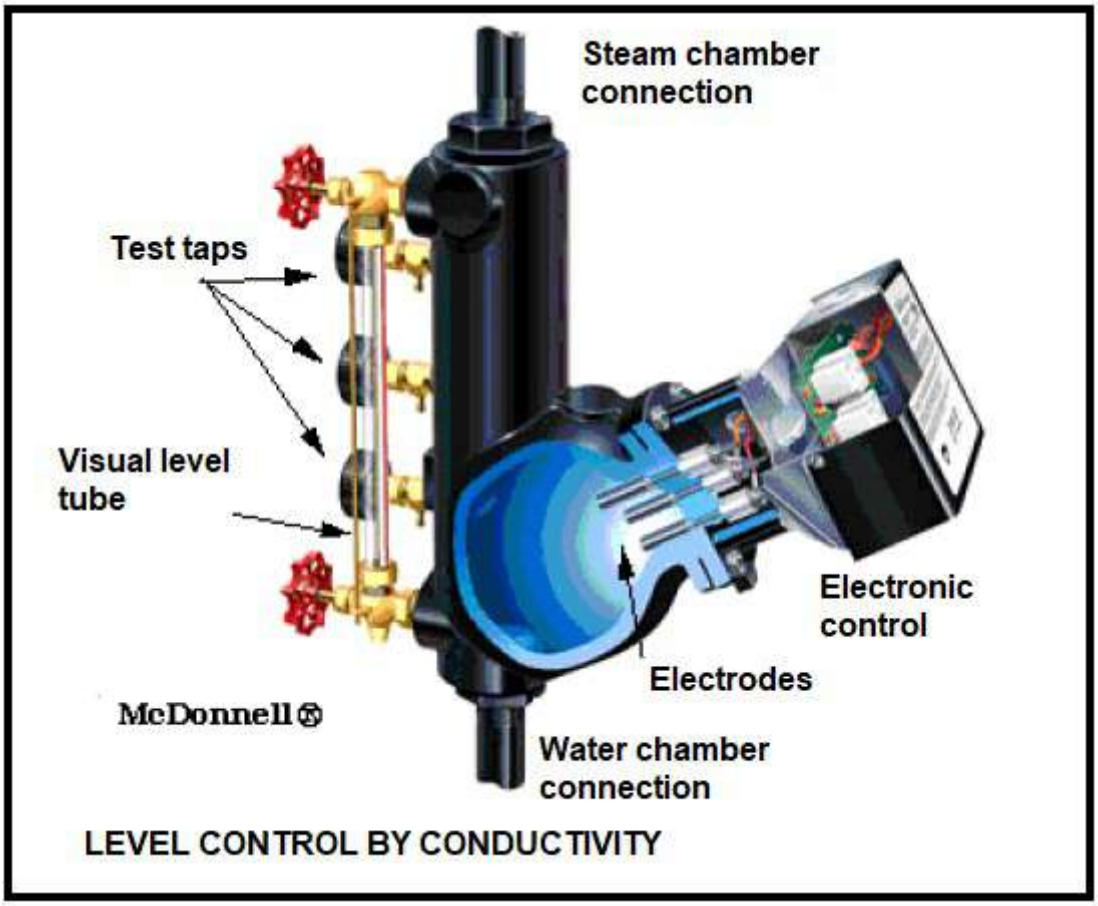
Deposits on the electrode insulators of level control systems

When electrodes are used in level control systems, there is a risk of failure due to both lack of insulation (short circuit) and lack of water continuity due to low salinity (pure water is not conductive, condensate is almost pure water) or the presence of oils that insulate the electrode.

In my personal experience (CWT), I can say that these electric controls (which operate based on water conductivity), which were very popular years ago, have been phased out due to the risks involved (many boiler accidents were caused by these level controls,

since the conductivity of boiler water is highly variable, especially within the level repeater or copying tanks, where condensate, which has low conductivity, tends to accumulate, making it necessary to operate with high electrical "resistance," i.e., low water conductivity).

Therefore, the system must account for this situation and address the problem of insulator fouling, both internally and externally). The insulators tend to become fouled and cause false water level readings (we recommend cleaning the insulators, internally and externally, every 6 months to a year).



Another cause of level control failure is the current trend of placing level controls on a large-diameter repeating column (this "pipe" that acts as a repeating column tends to become clogged as it fills with sludge at its lower end.

Since the sludge suspended in the water enters the base of the repeating column, it settles because the water moves very slowly due to the lack of internal circulation within the column. Steam condenses at the top and connects with the boiler water at the bottom, and level purging is insufficient to create a sufficient cleaning speed at the base of the column).

This failure of repeater columns is partially eliminated by placing a large diameter (1" or more) purge at the base of the column, in the shape of a T (although I am not in favor of repeater columns, they are energy inefficient; at the end of the year, the thermal losses due to their large exposed surface

cost about 1,000 liters of liquid fuel or 1,100 m3 of gas or 3.5 tons of firewood 25%H.b.h).

2.- Lack of Water Supply

A lack of water level is very serious. Even with the fire out, it can cause tubes to loosen or localized overheating (leading to corrosion, fatigue, cracks, etc.).

As we have seen previously, we must prevent the boiler from losing water level under any circumstances. Therefore, we must do the following immediately:

a.- If there is no feedwater: turn off the fire and shut off the steam.

b.- If there is a power outage (the feedwater pump is not working and there is no auxiliary feedwater supply: injector or alternative pump): **turn off the fire and shut off the steam to prevent the boiler from emptying and exposing the tubes or other heating surfaces.**

Insufficient water supply, if the burner doesn't shut off in time, can lead to boiler failure (due to burnout) or even an explosion.

This can occur whether water enters the boiler while it's overheated or simply due to a failure of the pressure vessel as the material becomes unable to withstand the internal pressure. This is the most common failure (and can happen for many reasons).

HOMO-TUBULAR BOILER FIRE WITH LOW WATER LEVEL

3.-Boiler Leakage Failure

This could be a water or steam leak inside the combustion chamber or flue (perforated tubes, loose mandrels, cracks, etc.), or a leak in the outer casing (caps, manhole, casing cracks, connections to the boiler, etc.).

Turn off the burner, maintain the water supply until the boiler cools down, and allow air in if necessary to extract or expel the steam through the chimney. Release steam through the safety valves or other outlets (to reduce the steam pressure pushing the leak to the outside).

As always, allow the boiler to cool, trying to maintain the water level (if possible).

4.- Water Level Variations

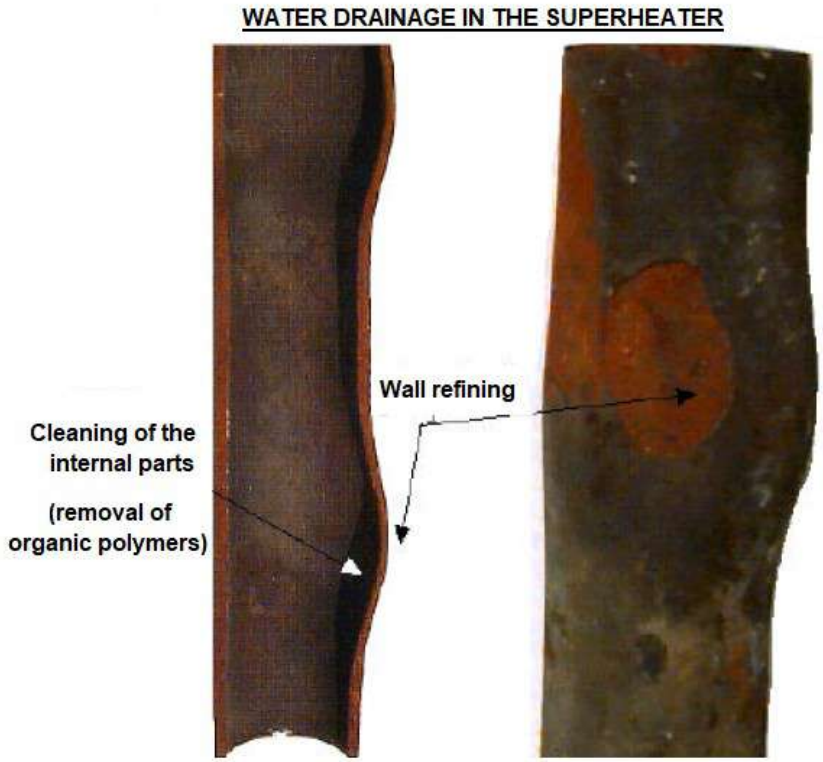
Abnormal variations in water level indicate the possibility of several problems:

a- Excessive (or momentarily excessive) steam consumption. This causes water to be drawn into the steam and can even lead to a low water level in the boiler (a sudden "priming" of water by the steam). Slightly close the steam valve until the level returns to normal (notify production to monitor consumption rationally).

b- Water chemical limits not respected (there may be a high concentration of dissolved or suspended solids, or both, contamination by oils or greases -organic matter-, very high pH, very high alkalinity, etc.).

Purge down the boiler until the levels return to normal (preferably use continuous or surface purge, purging thoroughly, or perform a bottom purge with the burner preferably off or at low heat to remove suspended solids: sludge).

Also purge the levels, especially the electronic ones with conductivity electrodes.



c. Design problems.

In boilers with steam drums or gas generators, if the water circulation (water downpipes) and/or the discharge of the steam produced in them is insufficient, level fluctuations occur.

This is because the tubes in the drums or gas generators tend to vaporize and displace the water inside during periods of high combustion, exacerbated by physicochemical problems in the water. This results in water being displaced into the fire-tube boiler.

Initially, this causes a high level, preventing water from being fed into the boiler. Then, when the water re-floods the drum or gas generator, a low level occurs (the burner shuts down).

This can lead to unstable boiler operation, with shutdowns due to high levels (if equipped with a high-level cutoff) and low levels (which all boilers have).

When the boiler lacks purge, or there are other chemical limits that are too high (pH, alkalinity, etc.), or some "oils" enter the system, or if the gait is very "strong", this problem worsens.

The aforementioned faults (including c) can lead to a lack of internal boiler water circulation, causing insufficient cooling of the heat transfer surfaces, which, when overheated, can crack or deform due to boiler pressure.

In this case, the combustion chamber of the fire-tube boiler can collapse (cases a and b), since on the fire side the temperature is between 1400ºC and 1600ºC (2912°F) and the metal should not be subjected to more than 450°C (842°F) or less.

This is the job of cooling the water on the water chamber side, whose temperature - the saturation temperature at the working pressure - generally does not exceed 200ºC (392°F) or less. But if the water does not "touch" the metal of the combustion chamber to cool it, due to excessively large bubbles or foam, the metal's temperature rises beyond what the pressure can withstand and it collapses.

"SODIUM ATTACK DUE TO CHEMICAL TREATMENT FAILURE"
Note the thinned lips (when caused by indentations, the lips are thick without stretching)
Breakage due to internal sodium accumulation

"SODIUM ATTACK DUE TO CHEMICAL TREATMENT FAILURE"
Breakage due to internal sodium accumulation
Note the thinned lips (when caused by indentations, the lips are thick without stretching)

Generally, internal circulation failure is due to insufficient purging (very high alkalinity, very high pH, very high TDS, etc.), or contamination with elements that alter the water's surface activity, usually organic elements, which in very small quantities produce a significant change in the water, causing foaming.

However, contamination can also occur with inorganic elements from the process, as in the case of dairies or other factories where alkaline elements such as soda are used for equipment cleaning.

Faced with these problems, the first thing observed is a fluctuation in visual levels above normal, so these elements should be purged immediately, especially with the purge valve fully open until the levels stabilize.

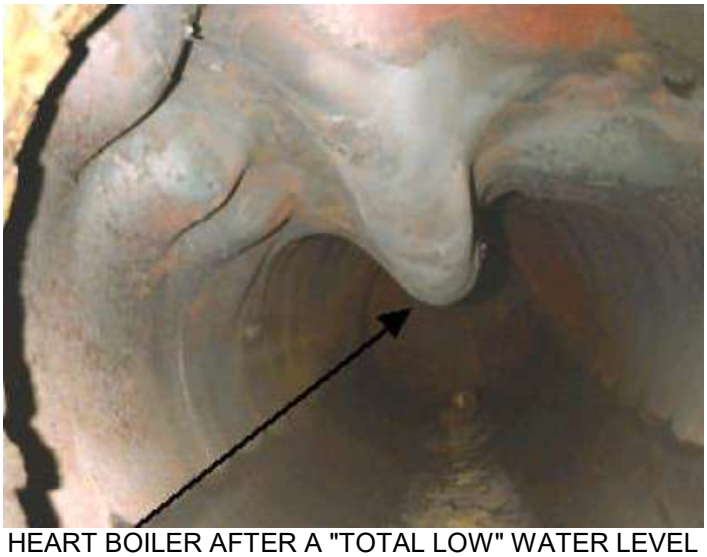
This fault is magnified the higher the combustion rate of the boiler (so it is advisable to lower the steam production, until sufficient purging has been carried out and the reason for the problem has been investigated, by checking the chemical values of the boiler water and feed).

A similar, but not identical, failure to when the boiler runs out of water but the burner remains lit.

BOILER HEART COLLAPSED DUE TO CIRCULATION FAILURE

When the boiler runs out of water and the combustion chamber collapses, a balloon-like "pocket" usually forms over the top of the chamber where the flame is most intense (approximately 1/3 of the length of the burner chamber). In addition, the upper tubes also overheat, twisting due to excessive expansion and often popping out of their mandrels. This results in noticeable excessive overheating in the steam going to the factory, which "burns" any combustible material on the steam pipes, even before the steam pressure has dropped.

In water-tube boilers, these failures cause the tubes to "break" above the furnace, meaning they are more exposed to the flame. This manifests as "balls" or "corns" of fuel in the areas of the tubes most critical for heat transfer. All these problems worsen as the heat transfer surfaces become fouled.



HEART BOILER AFTER A "TOTAL LOW" WATER LEVEL
View from the burner side (pocket formed due to lack of cooling)

If we observe the appearance of furnaces deformed by "low water level" and "circulation failures," we will see that not only is the color of the metal different—in "low water level" it appears more like "burnt metal"—but in "circulation failures," the furnace doesn't fail exclusively from "top to bottom," but can also fail laterally.

There are lateral depressions, which don't necessarily indicate that the furnace overheated more in the upper part, but rather in the areas that are more difficult to cool, that is, where the water has mostly "separated" from the metal due to a "vapor blanket" that insulates it.

This is very noticeable in "torsional chambers," which are an extension of the furnace, in an area of high heat transfer, where, more than deformation, there is often "thermal fatigue" that causes the furnace to crack due to repeated overheating, as well as in the secondary air passage pipes.

d. Combustion Problems

Combustion problems can also be reflected in fluctuations in the water level. In this case, there may be poorly controlled combustion (excessive or shifted combustion) or combustion altered by problems in the combustion chamber or gas passages (broken baffles, fallen refractory linings, etc.), which disrupts internal circulation.

Observe the chimney temperature (if it is the same as usual, if there are smoke readings, etc.). This situation can also lead to failure due to poor internal circulation of the boiler water, with local overheating of the material and subsequent failure due to lack of cooling.

Reduce the combustion rate until adjusted or repaired.

5. Fire in the Boiler Room:

If a fire breaks out in the boiler room, at the burner, or in the vicinity of the boiler: turn off the burner, leave the feed water supply running for as long as possible, and partially close the steam valve to prevent the boiler from emptying. (Obviously, if water is used to extinguish the fire, the electrical power must be cut off.)

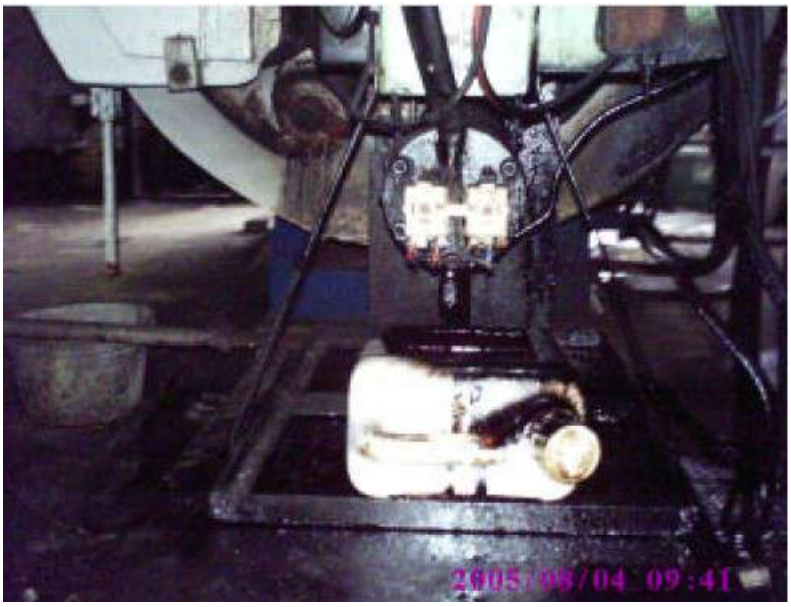
Special attention must be paid to the means of extinguishing the fire, given the variety of fuels used today. The use of water must be very controlled, as there should be no electricity present in the area where water is being used, and sudden cooling of metal structures is not advisable (as it can cause them to deform).

For liquid fuels, it is advisable to have systems using sand, water with foam, powder, and CO2. In some cases, water in the form of spray or steam should be used (when the fire forces the extinguishing of the internal combustion of cellulosic materials, so as not to cause a thermal shock that could lead to further damage).

This issue must be carefully studied before an incident occurs, ensuring not only the means for extinguishing or smothering the fire, but also that all necessary support equipment (personal protective equipment) is available, including alternative escape routes from the boiler room.

It is advisable to have a fire brigade, with the boiler operator as the leader in the boiler area.

It is also essential to have an external electrical power cut-off point outside the boiler room.



Medium Loss and Oil Spill

6. Water in the fuel: (Fuel Oil and similar fuels)

Variations in the flame are noticeable: instability, sputtering, smoke in the chimney (whitish to blackish), and combustion tends to stop.

Sometimes it is possible to continue "burning" this fuel (with excess air despite poor atomization), but once it has been determined that the cause is water, it is preferable to stop and drain the service tank and the supply tank (remove the water from the bottom of the tanks using the valves provided for this purpose or install a pump that draws water from the bottom—if necessary, heat the fuel oil and let it settle for a few hours).
Clean filters and water traps.

The use of fuel additives makes it difficult to separate water from the fuel (if the contamination is less than 1.5% water, this water that integrates into the fuel burns without problems and even promotes combustion).

Therefore, it is advisable not to use additives if the presence of abundant water in the tanks is very frequent.

In some cases of abundant water with additive-enhanced fuel oil, it becomes necessary to completely remove the fuel oil, since it does not separate the water no matter how much it is heated and allowed to settle.

There are some catalytic cracking fuel oils that are heavier than water (density 1 or higher), which do not allow water to be separated. In these cases, it is recommended to add 20% diesel oil, mix, heat, and let it settle to separate the water as the density of the new mixture decreases.

To detect water in fuel:
take a sample of the fuel oil in a test tube (laboratory glass), fill it halfway, and gently heat the bottom of the tube with a flame (rotating it). If water is present, steam bubbles will form and tend to rise. Alternatively, take a sample of the fuel oil in a container and introduce a hot electric soldering iron (only the copper tip) or a heated iron rod (or flat iron) heated to the first color (pale blue). If, upon insertion, "squeaking noises" (like water in a frying pan) and bubbles appear, water is present.

Otherwise:
have the fuel tested by a specialized laboratory (usually the same company that supplies the fuel).

Only by being mentally and physically trained, and knowing the boiler room and the boiler inside and out (with your eyes closed), will we be able to act correctly and in time.

Let's not forget that when there's a power outage (a cut in electrical power at the industrial plant) or when there's steam in the boiler room atmosphere, we often won't be able to see clearly: if the "boiler" doesn't resolve the situation, it's unlikely that someone else will be able to do so without the proper knowledge, and most likely they'll cause a bigger accident by performing the wrong maneuver.

Stoker Boiler Handbook 2011, C.W.T. – CH6 EMERGENCIES

It can be said that every 50 kg of superheated water (at 10 kg/cm², 142 PSI, 183°C, 361°F) can produce an explosion equivalent to 1 kg of gunpowder.

This effect is due to the volume that the steam occupies when it expands at atmospheric pressure.

BOILER EXPLOSION DUE TO LOW WATER LEVEL

The recommendations in this chapter are suggestions for action,
but each boiler and each installation should be thoroughly analyzed beforehand to determine the appropriate response to each emergency.

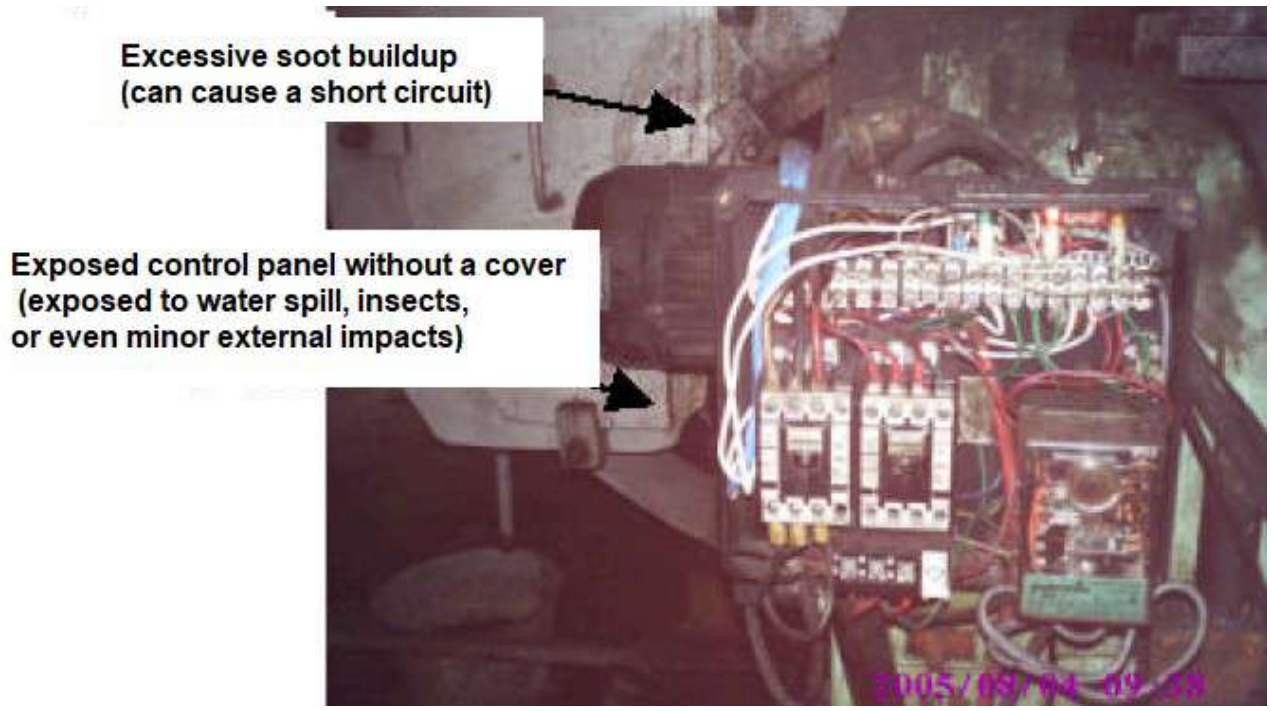
Don't forget to have the necessary fire safety equipment, personal protective equipment, and tools readily available for these emergencies: a boiler emergency doesn't leave much time to think and act.

Boiler hazards are directly linked to inadequate equipment maintenance, especially regarding the condition of the water-contact surfaces (scale and sludge buildup) and safety features (primarily proper water levels and safety valves).

A clean and well-maintained boiler is efficient and safe. A trained and conscientious boiler operator can address any risks that could endanger their safety.

As in all human activity, ORDER AND CLEANLINESS are the base of the pyramid for the best productive results, taking care of human life and the environment.

Effect produced by the explosion of a container
subjected to pressure with steam (fat digester)


Excessive soot buildup
(can cause a short circuit)
Exposed control panel without a cover
(exposed to water spill, insects,
or even minor external impacts)

A BAD EXAMPLE OF BOILER MAINTENANCE

CHAPTER 7: BOILER MAINTENANCE Part 1

We have seen that boilers are subject to a series of actions that make it necessary to attend to them carefully, especially to avoid more serious problems.
We will divide the topic into:

1. Mandatory maintenance.

2. Routine maintenance:
a) of the boiler room and outdoor boiler,
b) routine maintenance,
c) of the fire zone,
d) of the water and steam system.

3. Hydraulic inspections and tests.

1-Regulatory Maintenance

The boiler and boiler room are subject to laws and regulations that must be complied with. To this end, the boilers undergo periodic inspections (annual inspection and a hydrostatic test every four years, carried out by the relevant Ministry) and the personnel operating the boilers are monitored to ensure they hold the appropriate certification (issued by the relevant Ministry).

The minimum safety and maintenance requirements are checked during these or occasional inspections.

The room must meet minimum criteria, which fall under National, Departmental, Insurance Company (accident prevention), Fire Department, and other regulations.

It is advisable that all these regulations be compiled and kept up-to-date by the company using the boiler to ensure they are informed.

Repairs to the pressure vessel (it is advisable that these be carried out only by registered and authorized workshops), relocations, sales, etc., must be reported to the competent regulatory body.

Boilers have a logbook (issued with the initial manufacturer's certification) that must be kept in a safe place (so it is not lost), where boiler inspectors record the repairs and inspections carried out.

The boiler has a plate stamped (engraved) with the date of each inspection (stamps made only by the inspector, not by the user).

2-a) Boiler Room and Boiler Exterior Maintenance

The boiler room is the boiler operator's "home." We all like our "home" (the place where we spend 8 hours a day, many days a year, and a large part of our lives) to be clean, painted (with the colors specified by industrial safety standards), and with tools and equipment organized and readily available for any emergency.

Avoid leaving papers, rags, or tow in areas that could cause fires, as well as oil and fuel stains that can not only start a fire but also cause a slip (the well-known principle of ORDER AND CLEANLINESS).

Maintaining proper ventilation (especially if gas is used as the primary and/or secondary fuel) and adequate lighting (both natural and electric) contributes to a more comfortable and safer life.

The electrical installation must be in good working order; it is the point where fires or electrical shocks (electrical discharges) can originate, which can cause fatal shock. Electrical equipment must be properly grounded (to discharge induced or accidental voltage).

Staircases and hallways, as well as their safety railings, should be kept in good condition. These are areas where it may be necessary to walk in the dark due to insufficient light or because the room is filled with steam.

Repair all water and steam leaks (fixing valve packings and pump seals), reporting any situation you don't understand or can't handle to the supervisor.

Do not attempt repairs that could cause further damage, such as tightening a plate or threaded part under steam pressure without proper training or conditions.

Staircases and hallways, as well as their guardrails, should be kept in good condition. These are areas where it may be necessary to walk in the dark due to lack of light. Keep the boiler clean (its casing), the level indicators, and its lighting, and do not allow water or steam to fall onto the boiler (this will cause the casing to rust and pit, common corrosions on caps, plates, etc.).

2-b) The routine

-Maintain constant monitoring of **water levels and pressure**,

-**Control the fire/flame** to prevent poor combustion: smoke or excess air,

-**Purge the level controls every 4 hours** (at least once with the burner lit to check for "low level cut-off").

-Check the level of the **water supply tank**.

-Perform a **bottom purge once per shift** (every 8 hours) or as instructed, and monitor the operation of the continuous purge system (if used).

-**Add internal treatment chemicals**,

-Monitor the **water softener**, and “regenerate” it if necessary.

-**Monitor the burner** continuously, cleaning slag and nozzles (atomizing tips) as needed.

-**Monitor localized temperatures** in the boiler, chimney, and any abnormal

gas fumes leaks.

-**Monitor fuel levels**: temperatures, pressures, minimum quantities (for pumping or ordering fuel), clean filters and purge water, add additives, etc.

-In the case of **gas combustion** (natural gas or other type), **maintain leak control**, both by "smell" and by other acceptable means (leak detector, soap and water test in the joint areas, etc.).

-Perform **checks on flue gases** (visual inspections: smoke and flame color in heavy liquid fuels; in wood-burning direct combustion,

-Ensure the **flame length** does not exceed half the diameter of the cylindrical firebox.

-In Wood gasifiers/Gas generators and other gases combustion, **monitor the composition of the flue gases**, including oxygen and unburned gases or CO).

-**Check the flue gas temperature** (which can indicate that the boiler is dirty, overheating, or has other combustion problems).

-Monitor **bearing temperatures and "noises"** (abnormal vibrations), motor amperages and temperatures, tighten belts, check for oil and grease leaks, and lubricate where necessary.

This will allow us to take timely action if a failure occurs, either to make the repair or to notify the person in charge, who will arrange for the replacement or scheduled shutdown of the boiler.

-**Record any new developments** and those that the relevant person on duty needs to know to continue the journey. A form or a notebook with numbered pages is very effective for this purpose (this makes the stoker's job easier and avoids many potential misunderstandings).

-Check the safety elements, such as the safety valves, by manually opening them to the working pressure at the appropriate time (at low steam production), check the auxiliary feeding elements (pumps or injectors), purge the level indicator valves, check the fire equipment, etc.

Let's not forget that **when we start a cold boiler, we must thoroughly check the above and proceed to heat it as slowly as necessary to reach**

the working pressure (to avoid causing damage to the boiler structure, both the pressure body and refractories, since **when heated there are significant expansions: 1 mm or more per meter for every 100ºC (212°F) that the temperature rises.**

Roughly speaking, when we start a cold boiler, for a small boiler (500 kg/h of steam), start with at least one hour of low heat. Increase the heating time by half an hour for every 500 to 1000 kg/h increase in steam capacity, depending on the type of boiler (primarily the type of fuel and combustion chamber). Keep the atmospheric valve open.

Rapid heating is ultimately more expensive due to repairs or premature boiler aging (fatigue or accelerated thermal stress).

The atmospheric valve will remain open until the working pressure at which the boiler will be connected is reached. This ensures more even heating of the water mass.

In the case of boilers with a steam superheater, it will be kept in constant steam circulation by releasing steam through the discharge, ensuring that the steam circulation is not lacking (the minimum necessary to prevent the steam temperature from exceeding predetermined limits), as this can cause the boiler to "burn" due to the high temperature of the tubes.

Once the pressure is reached: slowly release steam (heating the steam distrobution pipes) and gradually increase combustion to maintain the pressure.
Monitor the internal chemical treatment, take water samples, and perform the minimum analyses necessary for good steam quality (clean and dry steam) and to prevent scale buildup and boiler corrosión.

The minimum analyses typically include:

Total Dissolved Solids, pH, and maximum and minimum values of the base products of the treatment: Phosphates, Sulfites, etc. Keep the water clear: free of suspended solids, oils, grease, etc.).

2-c) Fire zone

In this zone, we must maintain **regular cleaning** according to the type of boiler or fuel used.

Whether heavy fuel oil or heating oil, it produces a **highly insulating soot buildup** (exacerbated if combustion is inefficient).

The resulting heat loss, which increases the temperature of the flue gases (heat lost through hot gases), necessitates **periodic cleaning monitored by a thermometer in the chimney.**

This thermometer allows us to establish a maximum temperature limit for cleaning the flue pipes (brushing in smoke-tube boilers or blowing out in water-tube boilers).

These cleanings can also be scheduled by time: cleaning smoke-tube boilers every weekend, every two weeks, etc. Water-tube boilers must be blown out (with steam or air) every shift or every 24 hours, as deemed necessary.

In some cases, the chimney temperature does not reflect fouling, but rather the **pressure drop of the gases** (the gases have difficulty passing through the boiler), causing a decrease in the combustion rate due to insufficient draft.

In wood-burning boilers, the ash that adheres to the tubes also creates insulation that impedes heat transfer, which in some cases can be very significant, as the temperature of the gases increases and pressure drops.

These systems, which tend to become insulated, should be cleaned almost weekly (as in the case of gas generators, gasifiers), while in other cases, cleaning may be delayed for one or two months (direct combustion).

Ash also blocks the grates, fireboxes, and heat exchangers (air or water), causing heat insulation, but fundamentally, a loss of pressure or obstruction of the gas flow, reducing the draft to the boiler (thus limiting combustion due to lack of air).

This phenomenon is accelerated in some types of combustion and in all

when the wood has a high moisture content or has burned with insufficient air (producing a lot of CO, which indicates the expulsion of other elements through the chimney).

Therefore, grates and grates should be kept clean by removing them with the appropriate systems or by inserting compressed air bars or pipes to dislodge accumulated ash.

In gas-burning boilers, flue gas composition should be monitored, and the chimney temperature observed, as under certain conditions it can cause soot buildup that insulates the heat exchange surfaces (requiring immediate cleaning and correction of the combustion problem).

In "dual" burners (oil and gas), keep the heat exchange surface clean and remove any slag that may have formed during the period when it was used on oil (as it can be "dangerous" when switching back to gas, since there may be an ignition problem that causes a combustion chamber explosion).

Heat recovery units (air and water heaters) are easily cleaned if hot water and adequate drainage are available for the large amount of water required for cleaning.

This water can be from the feed tank, treated or untreated, but heated to over 80°C (176°F). The same feed pump can be used (with a valve for connecting the high-pressure hose), regulating the pressure to 4 to 5 kg/cm² (71 PSI) with a 1/2" nozzle.

When using hot water, and considering that the heat exchanger may be hot (since the thermal shock is minimal), be careful of burns.
Use all personal protective equipment (PPE).

2-d) Water and steam system maintenance:

Water treatment, purging, etc., are of paramount importance to prevent scale buildup or corrosion on internal surfaces.

Boilers that are stopped for days are at great risk of corrosion (mainly oxygen "pitting"), since when they lose pressure due to cooling, below 100ºC (212°F) they begin to have negative pressure (vacuum due to steam condensation) allowing air (oxygen) to enter, which with the temperature and certain conditions (the use of softened water without chemical treatment) quickly causes corrosion of the "pitting" type (mainly).

Boilers that are shut down for days are at high risk of corrosion, primarily oxygen pitting. As pressure is lost through cooling, below 100°C (212°F) they begin to experience negative pressure (a vacuum created by steam condensation), allowing air (oxygen) to enter.

This, combined with the temperature and certain conditions (such as the use of chemically untreated softened water), rapidly causes pitting corrosion (primarily).

Some boilers, used only two days a week with softened, untreated water, have developed leaks within three months of being new. Softened or condensed water (and rainwater), without proper chemical treatment, is corrosive.

We should never leave a boiler filled with this type of untreated water.

In other cases, when the boiler stops operating or due to condensate, water contamination occurs, causing corrosion that eventually perforates the boiler.

In addition to what was already mentioned **regarding oxygen pitting, these cases include boilers used for heating swimming pool water** (via heat exchangers, where water from the boiler heats the pool water).

Because these pools are chlorinated, the chlorine, upon penetrating the boiler and interacting with the internal conditions, causes pitting similar to oxygen pitting, but with an even greater corrosive effect.

PRESERVING BOILERS OUT OF SERVICE FOR LONG PERIODS

WET METHOD

When boilers are shut down for extended periods, regardless of whether their water is chemically treated, **they must be flooded with water,** leaving an elevated wáter tank working as “water seal” (to prevent air from entering and to maintain the water level despite fluctuating boiler temperature changes).

This seal should be connected to the OPEN atmospheric valve, with all other valves CLOSED.

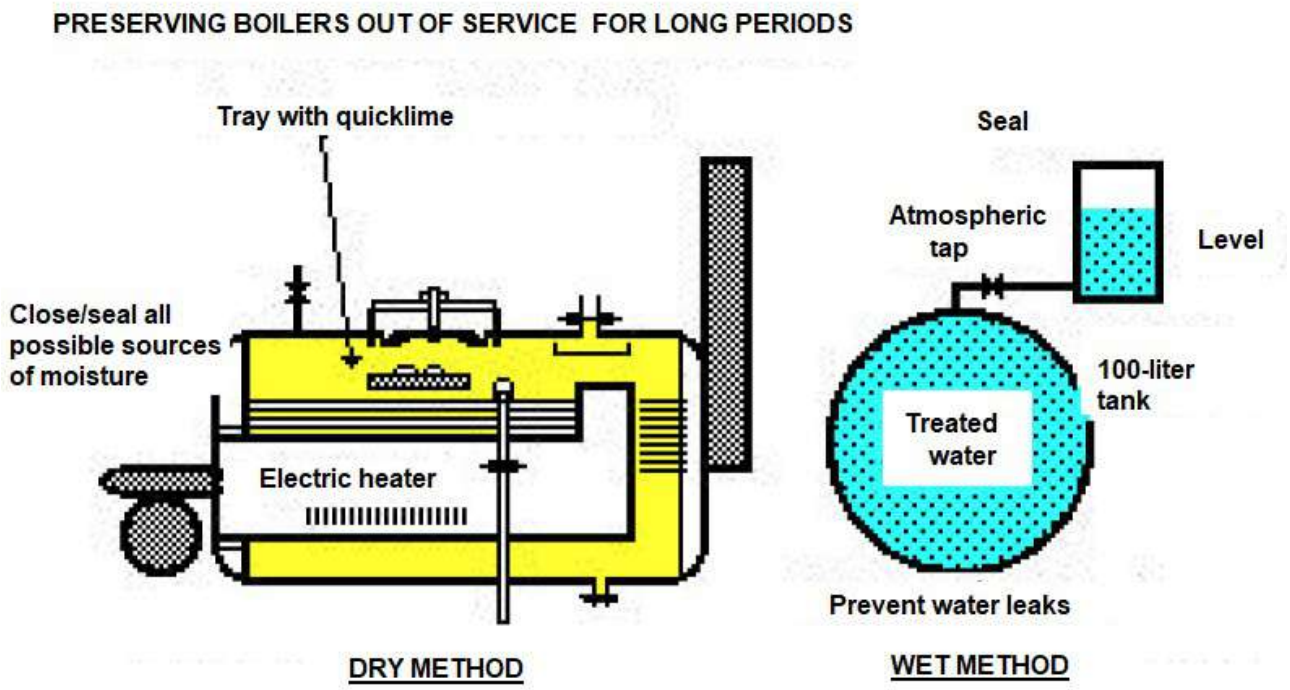
The “wáter seal”, a 20-100 liter plastic tank, should always be kept half full.

This prevents valve leaks that require refilling, as well as the possibility of steam pressure from another boiler constantly "filling" the shut-down boiler with condensate (due to valve leaks or insufficient steam retention).

DRY METHOD

It is very important to keep the boiler either flooded or completely dry. Dry it completely, with no moisture at all, using heaters or desiccant elements inside, such as quicklime or silica gel. Be careful with the lime; ¡it should not touch the metal of the boiler, as it is corrosive!

Dry boilers must be sealed to prevent moisture from entering if they do not have heaters to raise their temperature above ambient (preferably platinum-coated heaters).



BOILER CARE PERIODICITY

Boilers that are shut down must be checked periodically (every 15 days to a month) to maintain the desired conditions or values.

Boilers in operation must be opened, drained, and hosed down once or twice a year, cleaning the level controls and associated piping, checking pressure controls and their "pigtails," blowdown valves, etc.

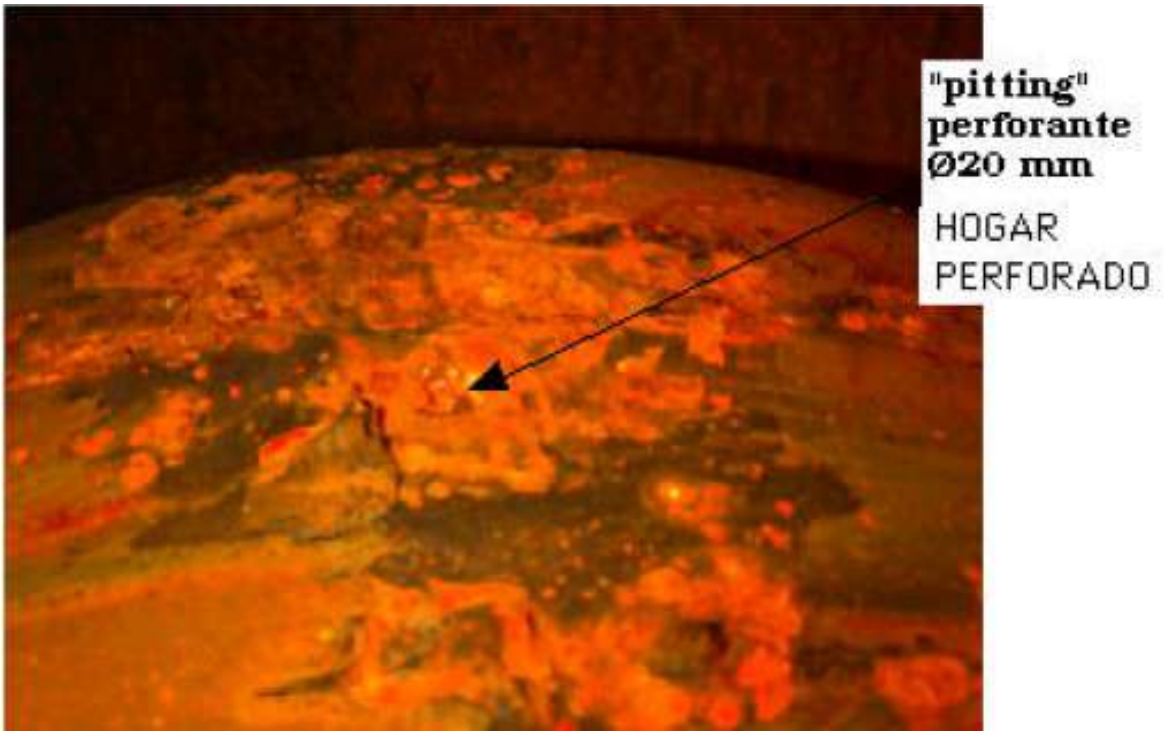
Take this opportunity to perform a visual inspection to evaluate the progress of the chemical treatment, observing for the presence of scale or sludge, corrosion, etc. (This will allow us to stop any treatment errors in time).
Replace the fusible plug (do not refill it yourself) in accordance with regulations.

CHEMICAL FEED WATER TREATMENT

Chemical treatment of boiler feed wáter isn't about "magic products"; its success depends on the skill of the boiler operator, the quality, amount and timing of the products used, and the guidance of the technician overseeing the treatment.

It's important to remember that the technician overseeing the treatment is only occasionally present at the plant and boiler room.

Therefore, the information this technician can convey to the boiler operator is of paramount importance, since the boiler operator will be the one performing the treatment and will be the only one on hand in emergencies, acting and informing the plant managers.

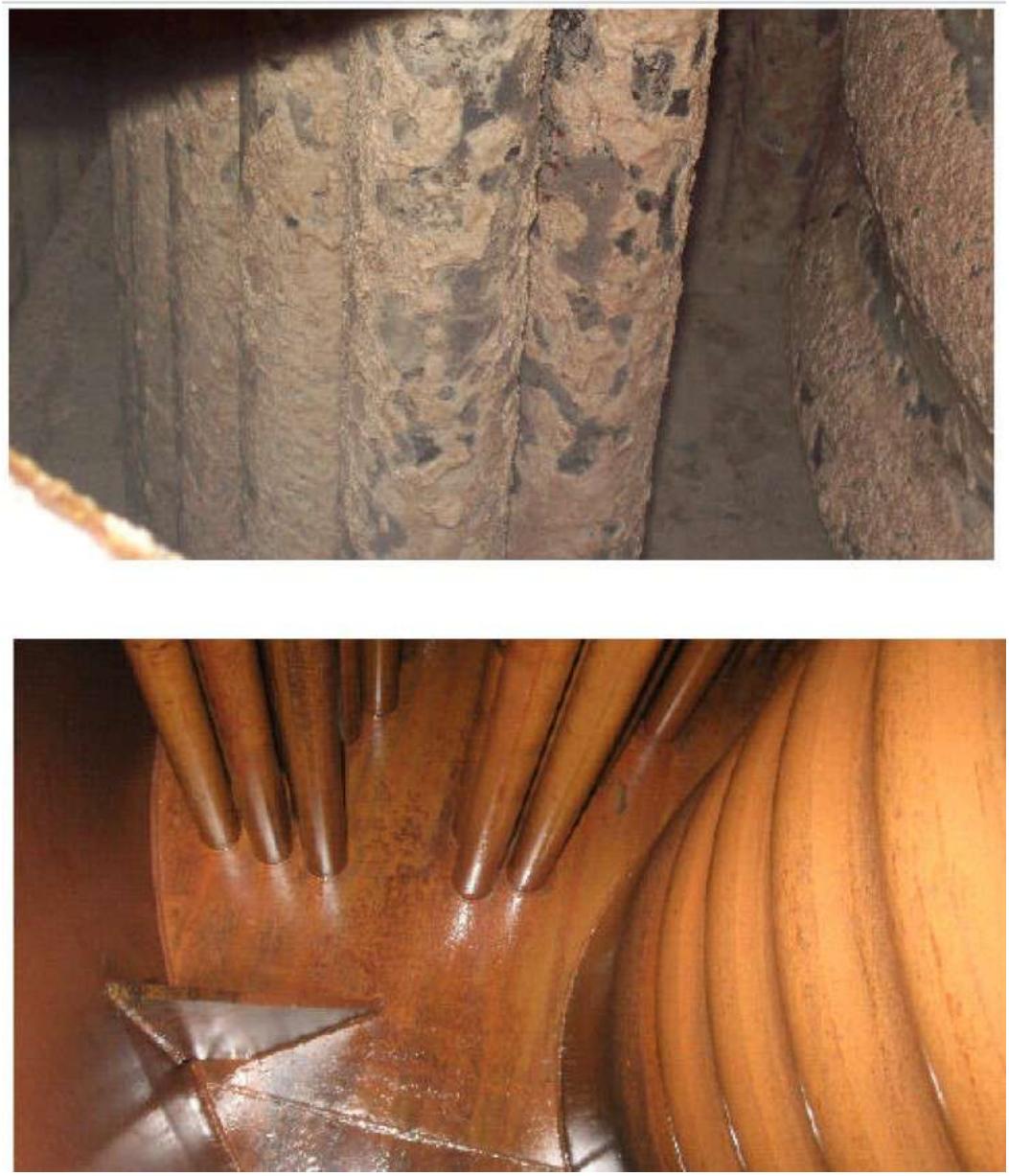


BOILER WITH "PITTING" CORROSION DUE TO POOL WATER CONTAMINATION
(New boiler, less than 1 year old; 20 mm deep pitting is observed in the boiler combustion chamber)

BOILER CHEMICAL CLEANING

It is advisable to perform a “chemical cleaning” every few years or as needed.

This chemical cleaning should be carried out by a qualified person, as it is an operation that carries risks and can cause premature aging of the boiler material (especially the tubes) or corrosion.



BEFORE AND AFTER THE CHEMICAL CLEANING
The boiler became scaled due to the use of a mixture of well water and surface water (rainwater). The boiler operator lost track of the water quality inside the boiler, and consequently, the necessary frequency of water softener regeneration and chemical dosing.

Some materials cannot withstand certain acids, and the best acids for these uses must be applied judiciously.

The experience of a qualified technician is essential previous and when performing boiler chemical cleaning, not only because of the possibility of uncontrolled corrosion or cleaning failure, but also because of the **risk of a hydrogen explosion**.

The use of acid in chemical cleaning of boiler metals causes the release of hydrogen, which, when mixed with air (oxygen), is highly explosive. In addition to other risks to human life (for those performing the chemical cleaning) and environmental hazards (spills, gases, etc.),

But if things are done properly, there's no need to fear chemical cleaning, since a boiler that is encrusted (with hard or muddy scale) not only loses performance, but also runs a great risk of "burning out," the tubes loosening on the mandrels, or the plates cracking, which becomes a permanent danger.

After chemical cleaning, the entire internal surface of the boiler must be neutralized, passivated, and mechanically cleaned (hosing and brushing if possible). Remove all scale, sludge, and other buildup.

To do this, remove all cleaning caps from the domes and collectors. Scale buildup can cause problems with water circulation and bottom valves.

After chemical cleaning (the acid neutralized, passivated, and mechanically cleaned)**, visually inspect (inside/outside) the boiler and then perform a hydrostatic test** (taking the necessary precautions to risk gases still inside, adequate ventilation as needed).

It is not advisable to attempt internal chemical treatment without knowing the condition of the boiler's internal surfaces.

DO NOT CONFUSE TERMS AND FUNCTIONS:
"WATER CHEMICAL TREATMENT" OF THE BOILER FEEDWATER WITH **"CHEMICAL CLEANING"** OF THE BOILER

While chemical treatments of the feedwater are intended to prevent scaling and corrosion, they are not for "cleaning the boiler."

Chemical feedwater treatments work by partially cleaning and removing scale deposits that obstruct the natural water circulation, causing localized overheating that, with continued operation, can damage the boiler or cause blockages in the safety system, blowdown, etc.

Given the possibility of scale or sludge buildup, it is advisable to inspect and hose down the boiler (cleaning the sludge from the bottom) as frequently as necessary. The correct approach to address this concern is chemical cleaning.

Efficiency and maximum steam production capacity are affected by the internal condition of the heat transfer surfaces: cleaning is cost-effective.

Stoker Boiler´s Handbook 2011, C.W.T. – CHAPTER 7: MAINTENANCE Part 1

For those who need to thoroughly study how to perform chemical cleaning, here are original documents of chemical cleanings carried out by my father, C.W.T.

We understand that this is a high-risk operation, both for the person performing the cleaning and for the person performing the task, and carries the risk of literally ruining a boiler.

Therefore, we felt it was not advisable to translate these C.W.T. documents from Spanish to English, but it would be a grave mistake to bury them on a hard drive running Windows 10 year 2025.

Several chemical cleaning C.W.T. (Carlos Walter Thomasset) experiences are contained here in about 10 PDF files: https://archive.org/details/limpieza-quimica-de-calderas-cwt-2008-1

It is the sole responsibility of the chemical engineer and plant technical manager to read and understand this material, its use, and its risks. 2025-12-07

Para quienes necesiten estudiar a fondo cómo realizar la limpieza química, aquí se encuentran documentos originales de limpiezas químicas realizadas por mi padre, C.W.T.

Entendemos que esta es una operación de alto riesgo, tanto para quien la realiza como para quien realiza la tarea, y que conlleva el riesgo de arruinar literalmente una caldera.

Por lo tanto, consideramos que no era aconsejable traducir estos documentos de C.W.T. del español al inglés, pero sería un grave error perderlos para siempre guardarlos en un disco duro con Windows 10 del año 2025.

Varias experiencias de limpieza química de C.W.T. (Carlos Walter Thomasset) se encuentran aquí en unos 10 archivos PDF: https://archive.org/details/limpieza-quimica-de-calderas-cwt-2008-1

Es responsabilidad exclusiva del ingeniero químico y del gerente técnico de planta leer y comprender este material, su uso y sus riesgos. 2025-12-07

CHAPTER 7: BOILER MAINTENANCE Part 2

BOILER FIRE SIDE MAINTENANCE

Boilers that have been out of service for extended periods must also be maintained externally, specifically on the flue gas side.

If a boiler is shut down for longer than a month, or during the winter months, depending on the type of boiler and fuel, the presence of ash and refractory material contaminated with corrosive elements can be addressed.

In some cases, these elements can be removed by washing the boiler with alkaline water (a small amount of soda ash in clean, hot water).

Do not attempt to use lime, as it is corrosive to iron in the presence of moisture. The boiler must be dried using indirect heat (electric or external steam), as igniting flames inside a "wet" boiler will cause corrosion.

The washed boiler must be dried immediately, avoiding keeping it "wet."

The drying time is crucial; it takes weeks, not days, because the water has penetrated the refractory material and is difficult to dry.

The boiler temperature must be raised to about 80°C-100°C (212°F) for several days, quickly (after a quick wash), since corrosion will always occur if there is moisture or water from the wash itself (this can be done with the boiler empty, with hot air, or flooded with treated water).

In winter months (for boilers exposed to the elements), it is necessary to maintain a temperature of a certain number of degrees Celsius (based on the wet-bulb temperature) continuously, using indirect heating (electric or external steam).

Never introduce steam into the boiler, as condensed steam is corrosive, even with chemical preservatives.

One technique could be to circulate the boiler water through an external heater or a heating tank, ensuring that the treated water from the boiler is always circulated, without coming into contact with air or losing water (under any circumstances).

(WET BULB TEMPERATURE, https://en.wikipedia.org/wiki/Wet-bulb_globe_temperature#/media/File:Analog_WBGT_meter.jpg)

One of the most common causes of corrosion in boilers that are not in use are seals failure, the loss of the neck valves and the steam distributor, which allows steam from other boilers in operation to enter. This steam, when it condenses on the top of the boiler, causes corrosion by displacing the treated water with condensate, which is corrosive.

Condensation from the roof or rainwater entering through the exterior of the boiler, such as the cover or casing, is also very harmful.

To prevent humid air from entering the boiler's combustion chamber, once it is dry and under some maintenance heating, close all air inlets and especially install a canvas or sheet metal "bonnet" to cover the chimney.

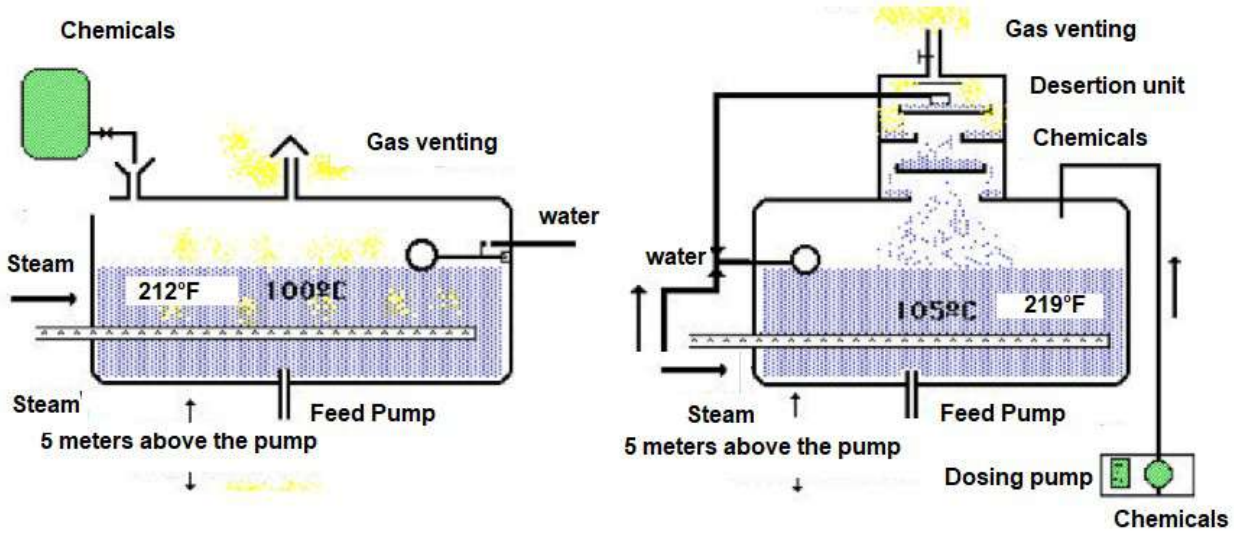
In some boilers, not only does the draft created by the chimney bring moisture into the boiler, but rainwater can also enter through the chimney itself, or the draft can reverse when the boiler is colder than the surrounding environment (allowing moisture to enter).

WATER TREATMENT CHEMICAL DOSING

It is evident that the dosing of chemicals for water treatment, specifically for internal boiler treatment, is generally more effective through continuous dosing than by adding them in batches or buckets (all at once per day).

Often, attempting to add all the chemicals needed for 24 hours at once to the feed tank causes significant harm, as it can lead to overdosing.

This can alter the water's surface properties, causing carryover or, worse, priming (a massive carryover of water that leaves the heat exchange surfaces uncooled and can cause water hammer in the steam lines).



TWO WAYS TO REMOVE OXYGEN FROM FEED WATER

It is also important to consider whether the chemicals will cause damage to the feed pump system. This includes abrasion from precipitates, attacks on the pump brass, attacks on mechanical seals, etc., since abrasion is the accumulation of mechanical and chemical effects.

For example, the use of **trisodium phosphate** in the feed tank can affect the pumps, as its precipitation, combined with water hardness, can cause erosion (it is usually injected directly into the boiler drum at high pressure using a high-pressure dosing pump).

Similarly, the introduction of **substances containing ammonia** in large quantities can damage the pump brass (especially the wear rings and bronze impellers).

The use of **polyphosphates** is more advisable to avoid the use of **orthophosphates (trisodium phosphate, disodium phosphate, etc.)**, as these do not precipitate as orthophosphates until they are inside the boiler.

Dosing pumps can be of the mechanical variable displacement type (mechanically driven by a piston or diaphragm) or the peristaltic magnetic type (using an electromagnet driven by an electronic circuit that generates a variable-frequency magnetic field in a coil, which in turn drives a diaphragm; the frequency determines the volume variation based on the number of strokes per minute).

Both pumping systems have flow direction, suction, and exhaust control valves, which tend to become clogged with deposits if soft water is not used to dissolve the chemicals.

The dissolved chemicals must be kept homogeneous using an agitator and should be introduced, after being dissolved, cooked, etc., through a funnel with a filter to prevent clogging of the pump filter or valves.

When using oxygen scavengers, it's important to note that continuous agitation can be counterproductive, as it introduces air (oxygen into the solution) which reduces the sequestering agent's effectiveness inside the boiler (because it has been consumed).

It's good practice to perform a chemical cleaning of the water feed pump, its suction filter, and the system once a month using 5% hydrochloric acid in a closed circuit for a few minutes, followed by a thorough flush with clean water (taking care to prevent any acidic solution from entering the boiler).

Generally, it's advisable to prepare the product in the dosing pump tank for each shift (6 or 8 hours), periodically cleaning the tank of any deposits that may accumulate at the bottom.

Dosing pumps should not be operated without product solution in the tank, as running dry can damage the diaphragms or pistons.

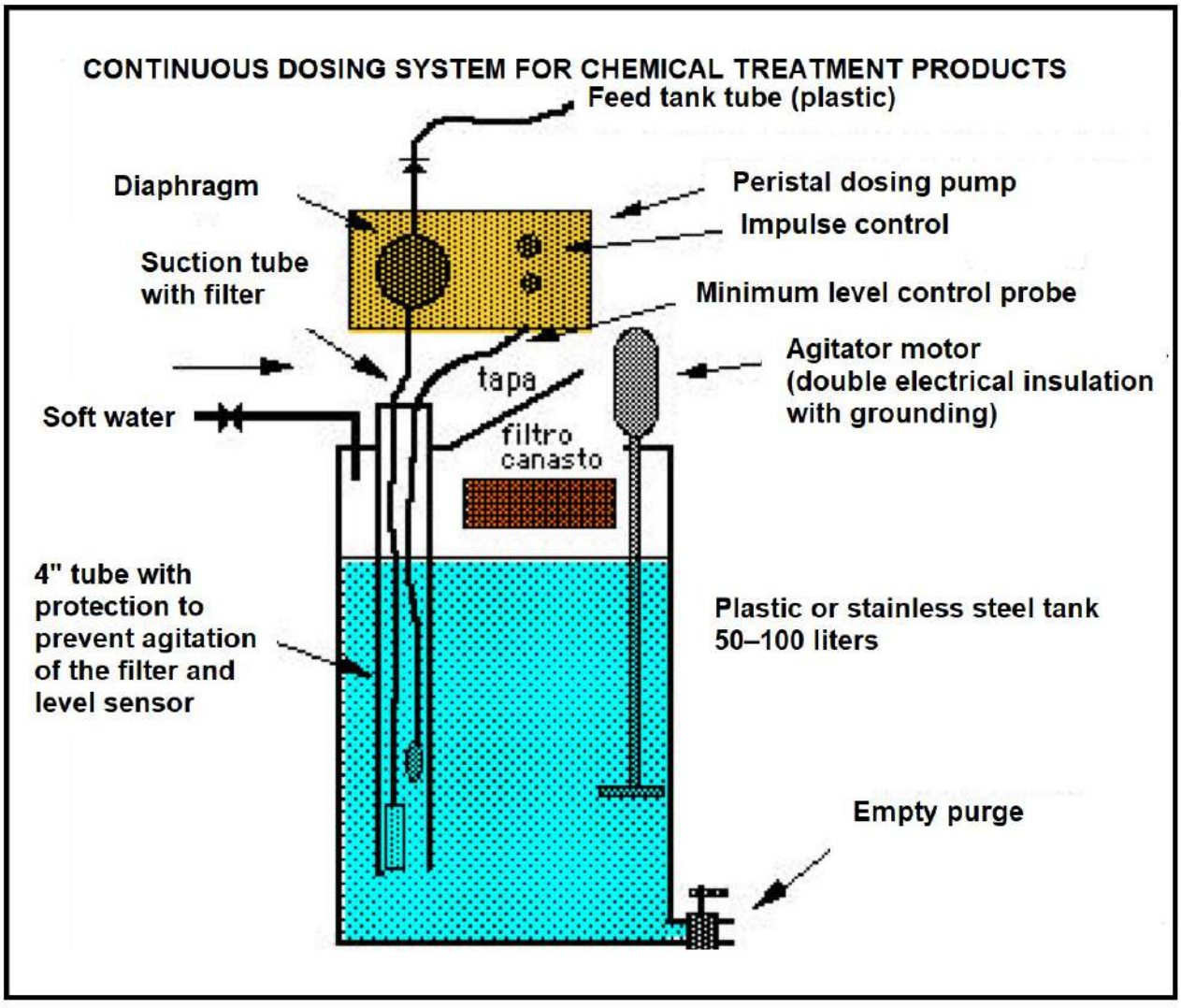
Therefore, they should be equipped with a minimum level float switch that stops the pump when there is no more solution to submerge the filter.

The tank must be made of an inert material (industrial plastic, stainless steel, etc.) that is easy to clean. The agitator must be mechanical, since agitation with air introduces oxygen into the system (which must be removed at all times).

Regarding agitation, it should not be continuous, as this introduces air into the solution (with the same problem as agitation with air).

In the following sketch, we have drawn a continuous dosing system with an electronically controlled peristaltic pump. We have detailed several elements to avoid maintenance and operational problems: a generously sized tank, a lid that opens halfway across the tank to allow both the addition of products through a mesh filter and easy cleaning of the tank's interior.

A 4" tube made of product-inert material houses the plastic suction tube and probe to prevent the pump from running dry (without solution), thus avoiding agitation and entanglement with the stirrer.


CONTINUOUS DOSING SYSTEM FOR CHEMICAL TREATMENT PRODUCTS
Feed tank tube (plastic)
Diaphragm
Peristal dosing pump
Impulse control
Suction tube with filter
Minimum level control probe
Agitator motor (double electrical insulation with grounding)
tapa
Soft water
filtro canasto
4" tube with protection to prevent agitation of the filter and level sensor
Plastic or stainless steel tank 50–100 liters
Empty purge

CONTINUOUS DOSING SYSTEM FOR CHEMICAL TREATMENT PRODUCTS

A drain valve and a soft water feed are also essential (otherwise, the filter and pump valves will become scaled, or sediment will quickly clog the filter). The tank must not be corroded by the chemicals.

Experience indicates that each shift (6 or 8 hours) should prepare its own chemical treatment dosage for the boiler feedwater, distributing responsibilities and ensuring proper preparation of the chemicals (pre-dissolving, heating if necessary, filtering upon addition, etc.).

These pumps and their suction system should be periodically washed with a 3% to 5% hydrochloric acid solution for a few minutes, followed by a thorough rinse before putting them back into service. A circuit can be established between a 5-liter plastic container into which the pump's suction and discharge lines are immersed. The pump is then run for 10 to 20 minutes, and then a thorough rinse is performed.

Although for corrective dosing in the form of a "shock," it is advisable to have a valve on the feed pump filter cap.

This allows for drawing from a bucket of dissolved chemicals to be introduced in a "sudden" or "shock" manner for instant corrections or the introduction of preservatives with the boiler stopped or about to stop, although if it is stopped, it is advisable to vaporize a little.

BOILER WATER SAMPLING:

The boiler water for analysis must be representative of the water inside the boiler.

I believe that purge water is not the most suitable, as it contains sludge that interferes with the analysis results. The tests will focus on dissolved salts (pH, TDS, alkalinity, chlorides, phosphates, sulfites, etc.). Suspended solids will also be monitored.

We will consider the case of low-pressure boilers (up to 15 kg/cm², 113 PSI). In these cases, the water extracted from the continuous blowdown can be suitable, provided the blowdown has a heat recovery unit to prevent flash steam. Flash steam will concentrate the sample, distorting the analysis results.

If the continuous blowdown does not have a heat recovery unit, it is advisable to use a chiller (refrigerated coil) to cool the sample below 100°C (212°F) to prevent concentration.

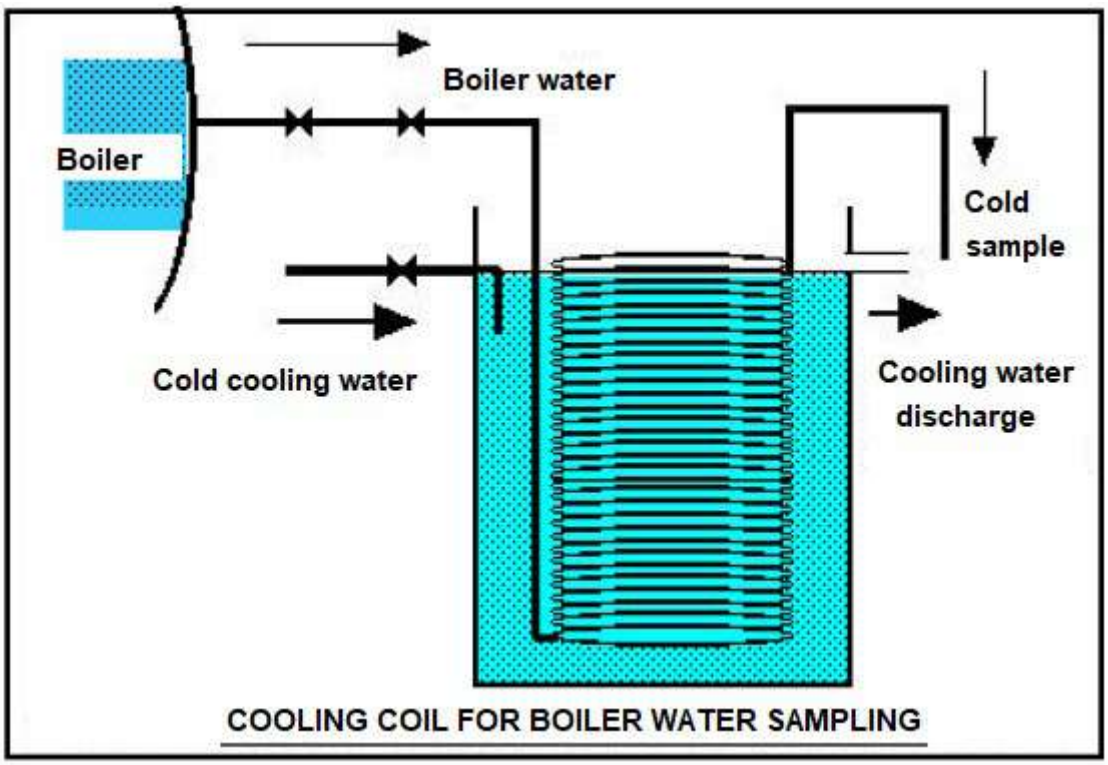
The sample should be taken from the continuous purge, as low-pressure boilers generally do not have a direct connection for sampling.

Just as cooling the sample in a coil is important, it is crucial that the sample be placed in a plastic "bottle," then tightly sealed to prevent air from entering, and unaffected by temperatura. Some plastic bottles are suitable, but if using metal-stainless steel bottles, be careful that the pressure generated does not cause burns or crushing upon cooling, as plastic bottles will only "swell" and shrink upon cooling, adapting to the internal liquid.

This sample should be cooled to room temperature and analyzed as soon as possible, thus avoiding alteration of the chemical values (due to contact with air).

Run the sample water through the coil before turning on the cooling water or filling the cooling water container. Rinse the "bottle" that will hold the sample several times.

Once full, seal the "bottle" tightly with the cap and place it to cool in a container or under running water, taking care that no external water enters, since cooling the "bottle" will create a vacuum that can cause water or air to enter (the advantage of the plastic "bottle" is that it will shrink and the vacuum will be minimal).



COOLING COIL FOR BOILER WATER SAMPLING

The coil can be a stainless steel or copper pipe, from 1/4" to 3/8", generally a diameter of 150 mm to 200 mm per turn is sufficient, generally achieving with about 15 to 20 turns, putting a shut-off valve against the boiler and a globe valve to regulate the flow of the sample to a value that the coil can cool.

3-Inspections:

The boiler should be inspected internally once or twice a year.

These inspections will allow for the detection of scale, sludge, and corrosion.

All internal parts subjected to mechanical stress (welds, stays, fluid inlets and outlets, etc.) and pressure (plates, casing, tubes, etc.) should be inspected. Stays tend to corrode at the weld in the hottest area (due to the thermal differential).

Steam zones can corrode, especially during periods of shutdown (boilers remain full to their normal level, allowing air to enter, the oxygen of which attacks the damp metal through partial condensation).

Typically, the tubes become pitted (perforated by oxygen when boilers are shut down without proper treatment).

SWIMMING POOLS BOILERS

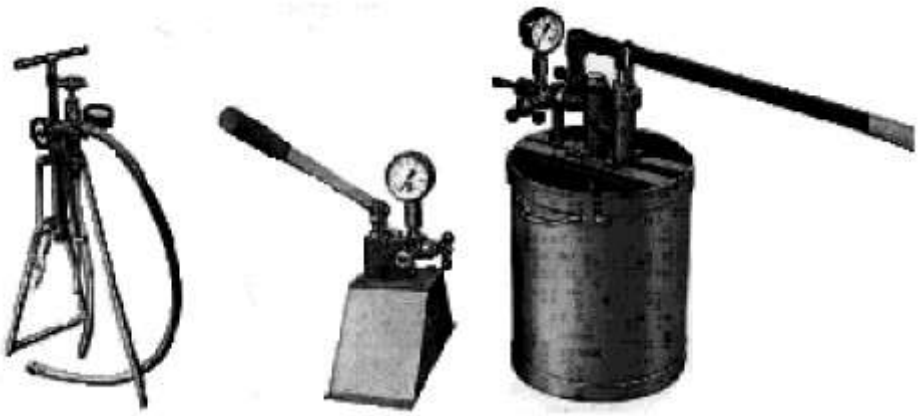
Boilers used to heat swimming pools are at high risk of corrosion if contaminated with pool water (chloride ions attack metal just like oxygen), making it highly advisable to perform internal chemical and visual checks of the boiler as frequently as possible, given that pool heat exchangers tend to develop leaks in a short time.

The use of hypochlorite in the water that feeds the boiler is a source of corrosion, both cold and hot; chlorine must be removed by means of activated carbon filters or by means of "sequestration" by excess sodium sulfites in the feed tank and the boiler.

HYDRAULIC TESTING

We must define a hydraulic test as; completely filling the boiler with cold water, removing the air from inside through the atmospheric tap, and then slowly injecting pressurized water until a certain pressure is reached.

Test pressure which must be predetermined and the pressure gauges used must be very precise.



HIDRAULIC TEST HAND PRESSURE PUMPS

This pressure, as long as it remains below the "ringing" pressure (the maximum design pressure at which the last safety valve should open), does not harm the boiler.

However, if we increase the pressure above the maximum design pressure, we are subjecting the boiler material to "elastic stretching" within a range where this stretching is reversible (returning to its original shape once the pressure is released).

But this elastic "deformation" can become permanent if we exceed the maximum permissible pressure or if we leave the boiler pressurized for too long (if a spring is left compressed for a long time, it will not return to its original shape).

From this, we must conclude that hydraulic tests should not be performed unnecessarily at high pressures (up to 1.5 times the design pressure in most cases for strength and leak testing).

And for those cases where we only want to know about leaks: that there are no leaks from the pressure vessel (or valves, levels, etc.), it is sufficient to

increase the pressure to the normal working pressure.

This hydraulic test can be called a leak test and can be performed as many times as necessary (always increasing the pressure slowly).

The hydraulic resistance test requires sealing all water and steam inlets and outlets, disconnecting all controls that could be affected by high pressure, and using a hand pump (or pneumatic or electric positive displacement pump with a relief valve) for hydraulic testing.

The boiler is filled with cold water (at room temperature, generally no less than 25°C (77°F), with the boiler also at room temperature, less than 50°C (122°F)).

This is to minimize variations in the standard pressure gauge due to pressure fluctuations caused by changes in the water temperature inside the boiler or the boiler itself. Changes in volume affect the pressure as the temperature rises or falls (due to the difference in the coefficient of expansion between water and the boiler metal).

This is something we are all used to seeing when we turn on the boiler with cold water at the normal level; we see that as the temperature increases, the water expands more and the pressure rises.

The pressure level is very important, and even very small temperature variations caused by air currents in the boiler room, often due to the natural draft of the boiler's chimney (which, depending on whether it draws in hot or cold air, can alter the pressure gauge reading if the test is delayed longer than necessary), can affect the pressure gauge reading.

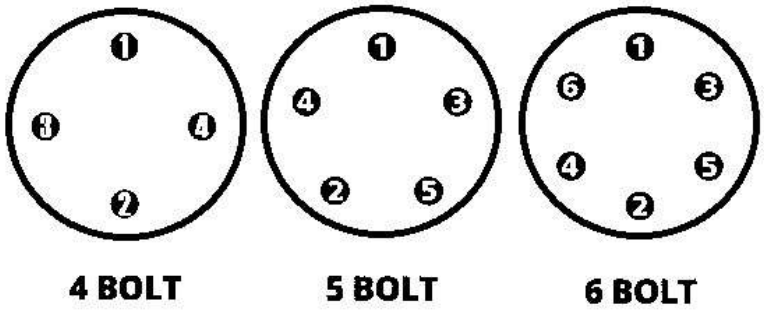
First, completely bleed the air through the atmospheric valve, and then gently and carefully increase the pressure with the pump, in stages, starting from a predetermined pressure.

BEFORE INCREASING PRESSURE, ENSURE THAT NO AIR REMAINS TRAPPED INSIDE THE BOILER. THIS WILL NOT ONLY GIVE A FALSE READING ON THE PRESSURE GAUGE, BUT IF A BREATH OCCURS, THE ELASTIC EFFECT OF THE AIR CAN CAUSE THE EXPANSION OF THE WATER OR PART OF THE BOILER, WHICH IS VERY DANGEROUS.

Careful attention must be paid to the maximum pressure and the accuracy of the pressure gauge, as there will be no limit to the maximum pressure except that established and monitored by the gauge.

Once the pressure test is complete, slowly reduce the pressure to avoid structural deformation.

After the test, it is advisable to **replace the seals on the manholes, head, and hand ports, especially for very high-pressure boilers**, as the seals tend to lose their elasticity due to permanent deformation from the crushing.



On seal caps gaskets, remember having the nuts/bolts “correct torque”, but also the “sequence”.

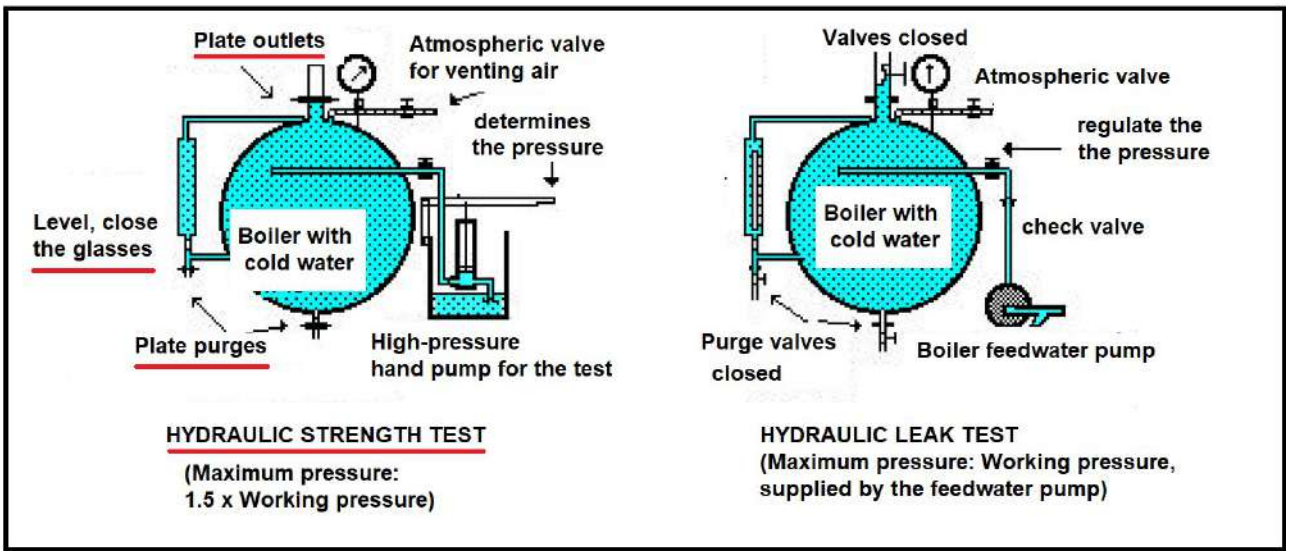
The hydraulic leak test simply involves venting the air through the atmospheric valve, supplying the boiler with water (even if it's warmer than normal, as long as there's no steam pressure) using the same feed pump until the operating pressure is reached.

The pressure is then regulated by adjusting the boiler's feed inlet or by turning the pump on and off (the pressure will not exceed the safety valves' setpoints).

At this pressure, the boiler can be left in presurized as long as necessary to inspect for leaks or make adjustments, as it's within the boiler's authorized operating pressure range.

The hydraulic test, used to assess the strength of the boiler body, subjects it to high stresses. If these stresses are left unchecked for an unreasonable period or varied rapidly, they can cause permanent deformations or fatigue, which will be the future cause of potential accidents due to failure of the pressure vessel structure.

Due to the above concepts, before performing the hydraulic resistance test, due to its importance: determine the maximum test pressure, compare the test pressure gauge with a standard pressure gauge, verify that the air extraction valve does so completely, ensure the boiler is clean inside and out, properly plate it, clear the points to be observed, etc.



As a guide, the maximum recommended pressures for hydraulic resistance testing according to some codes are (although in Uruguay, the ASME code is used, which is 1.5 times the design pressure: that is, the maximum permissible working pressure).

Another standard recommends the use of the following values, which seem more appropriate (since it doesn't seem "reasonable" to test a boiler with a pressure of 1 kg/cm² at 1.5 kg/cm²).

The following is applied in some marine environments, where a boiler accident could be catastrophic.

1. For boilers authorized up to 6.5 kg/cm² (92.4 PSI) working pressure, the pressure may be doubled during testing.

2. For boilers authorized between 6.5 kg/cm² and 13 kg/cm² (185 PSI), the test pressure may be up to 6.5 kg/cm² (92.4 PSI) higher than the authorized pressure.

3. For boilers authorized above 13 kg/cm² (185 PSI), the test pressure is 1.5 times the working pressure.

Generally, the test pressure is 1.5 times the maximum authorized working pressure, keeping in mind that very low pressure and high pressure boilers are subject to different values. (The inspectors will determine the test pressure during official tests.)

We must not overuse hydraulic strength tests (since repeated hydraulic strength tests cause material aging: fatigue, so it is advisable that they be supervised by a qualified boiler technician).

Increase and decrease the pressures slowly. Ensure that no abnormal deformation occurs as the pressure increases (do not continue increasing the pressure if an abnormal deformation or noise is noticed: investigate, making sure that all air has been properly vented; or in case of deformation, stop the test and decrease the pressure).

If necessary, have measuring devices available beforehand in any "doubtful" areas: calibrated steel wires, measuring tapes, etc.

Do not allow the maximum pressure to be maintained longer than necessary for visual inspection, deformation measurements, or pressure gauge readings.

Do not attempt to establish a higher hydraulic test pressure than specified for each case; this weakens the boiler in certain areas and could cause future failure.

Take safety precautions when performing a hydraulic test. A rupture of a boiler part or the spontaneous perforation of a casing, cap, connection, etc., can cause a serious accident by projecting metal fragments or high-pressure water.

Although there will be no expansion because there is no air, there will always be dynamic pressure due to the elastic stretching of the boiler when subjected to pressure.

The old "peen hammer test" is practically obsolete. (Striking the suspected area with a ball-peen hammer to trigger a forced "rupture" if the material appears suspicious, with the boiler subjected to the hydraulic test pressure, is not a recommended technique unless the person has extensive experience.)

A hydrostatic test is not a guarantee of safety for a boiler. (A boiler subjected to a hydrostatic stress test can suffer a breakdown within a few days of operation, such as a perforation in an area weakened by corrosion.)

Perhaps the explanation for this is that the boiler, under pressure when hot, experiences different stresses than when cold, or that the scale maintained its seal when cold but then detached due to thermal movements or the chemical treatment itself, etc.)

Visual inspection, measurements, and inspections using equipment (thickness measurements, X-rays, ultrasound, etc.) are very important, but perhaps even more important is the experience of the technician performing the evaluation.

Remember that a boiler is similar to an aircraft engine; if it has an accident, it is very difficult to predict its magnitude and exact timing. Therefore, maintenance and inspection schedules must be respected.

See the chapter on Structural Failures later for a guide to visual inspections.

CHAPTER 8: STEAM INSTALLATION BEST PRACTICES

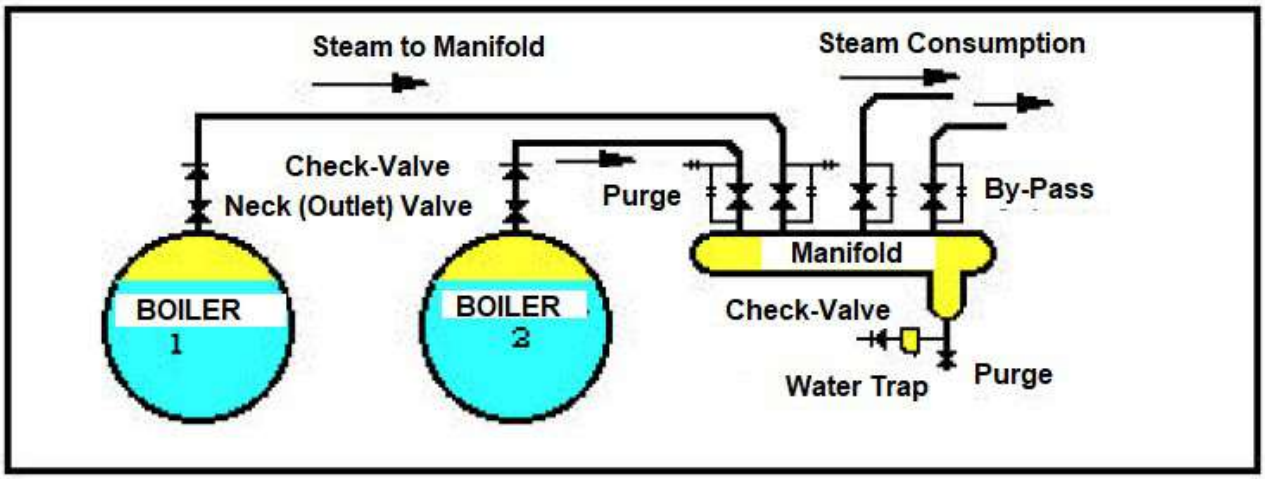
The "neck" valves (or steam outlet valves of boilers), when boilers are connected to steam distributors ("manifolds"), which may have valves upon connection to the distributor manifold due to other operating boilers, must have a small purge valve to keep the pipe empty of water.

If both valves are closed and the pipe is full of water for some reason (due to a leak in the valves), this water, upon heating, can expand and create a hydraulic pressure of such magnitude that it can cause the neck valve or the manifold valve to burst.

All large manifold valves must also have a small bypass valve—that is, in parallel—which will open first and close last, heating or draining to avoid thermal stress that could damage the larger valve.

When several boilers are connected in parallel (i.e., to the same manifold), it is advisable for **each boiler to have a check valve**. This allows each boiler to maintain its internal pressure, especially if the pressure drops.

Furthermore, if there is a leak or rupture in the pressure vessel, the problem will not be aggravated by steam entering from the other connected boilers.



Steam is carried through pipes to the locations where it will be used.

The pipe's dimensions or capacity to carry a specific quantity of steam, defined as kilograms of steam per hour, are determined for each steam pressure and quality (saturated or superheated at a given temperature).

This capacity is limited by the maximum steam velocity inside the pipe, which depends on the type of steam, the service provided, the pressure drop (pressure loss), and even the tolerable noise level of this flow.

To prevent damage to pipes and fittings, **the steam must be dry (without water droplets**, which will form as the steam cools due to heat loss from the pipes if it is saturated).

These droplets are like pellets or shot that travel at high speed and collide with metals or other materials, causing erosion or scratching, similar to mechanical corrosion.

Therefore, **the pipes must be insulated to prevent heat loss and steam condensation** (it is even advisable to insulate the pipe supports, using brackets that can be fully or partially insulated to avoid thermal bridges).

Flanges, plates, and valves must also be insulated, as their large exposed surface area causes significant heat loss. Removable insulating blankets can be installed on these surfaces for repairs. Additionally, the system must be dried (water removed) using water separators with steam traps.

The pipes must always slope in the same direction as the steam flow, in order to prevent the formation of water "pockets," which, if carried along by the high speed of the steam, instead of being "balls," will be a "cannonball" or **"water hammer" that will cause enormous damage when it hits the same pipe at the end of the line or a piece of equipment. Causing serious accidents in some cases.**

The most important benefit of insulation, over time, is fuel savings, which can amount to a very high value per year of losses.

For example: an uninsulated 3-inch pipe, 1 meter long, carrying steam at 10 kg/cm² (142 PSI), in an environment with an average temperature of 20°C (68°F), exposed in a place without wind or forced air, can produce an annual heat loss equivalent to more than 500 liters of fuel oil (this heat loss increases if there are winds or drafts).

The lack of thermal insulation on steam distribution pipes effectively reduces the boiler's capacity and thus its efficiency.

Let's look at a table of losses due to lack of insulation, on a flat surface, of dark iron (emissivity E= 1), in an environment at 21ºC, without "wind" (without air currents).

Hot iron Surface Temperature in °C	Temperature difference Difference °C (between iron and ambient)	Heat loss Kcal/m²/h
38	17	135
93	72	799
149	128	1772
204	183	3103
260	239	4895
316	295	7227

A similar table could be established for bare pipes, whose loss per linear meter will depend on the diameter and internal temperature of the fluid it transports, which, for example, if we consider the previous conditions, we would have:

Caño nominal	**Dif. temperatura ºC**	**Pérdida Kcal/m/h**
Caño 1/2"	93ºC	61,9 "
"	149ºC	136 "
Caño 3/4"`	93ºC	76 "
"	149ºC	169 "
Caño 1"	93ºC	93 "
"	149ºC	206 "
Caño 2"	93ºC	161 "
"	149ºC	356 "
Caño 3"	93ºC	231 "
"	149ºC	511 "

As shown in the tables above, insulation is crucial to prevent heat loss and condensation of saturated steam.

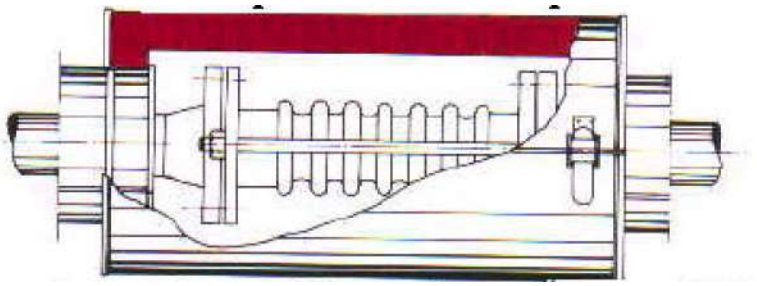
In the last reading for the 3" pipe, if we consider the temperature difference of 149°C, where the internal steam density is approximately 8 kg/cm², we see that we are condensing almost 1 kg of steam per hour per linear meter of uninsulated pipe. This is assuming an external temperature of 21°C and no drafts (drafts would increase the loss).

This is a very significant loss and a condensed inconvenience that causes all sorts of problems: it interferes with regulation and causes erosion of the regulating valve seats, it causes water hammer if not properly extracted, it reduces the pipe's cross-section if it doesn't have the correct slope, it causes corrosion by dissolving acidic gases, and it affects the transfer.

The fact that a pipe is "perfectly" insulated does not mean it won't lose heat, but rather that it will lose less heat. Valves, joints, and flanges without insulation cause significant heat losses, which increase as the operating temperature (i.e., steam pressure) rises, and depending on the location where it is installed (protected from wind, rain, etc.).

The insulation of these fittings must be designed so that they are easily removable, and that if steam or water leaks occur, they must be channeled to the outside, not only for immediate repair.

but also because if these leaks occur within the insulation, it ceases to insulate and, moreover, areas of severe corrosion are caused by the presence of moisture and oxygen.

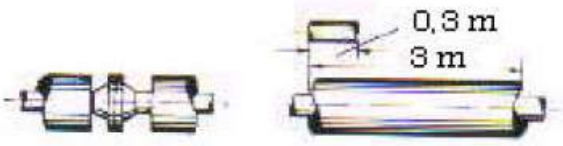


The losses through expansion joints are significant.
Always allow for proper expansion/contraction of the joint.

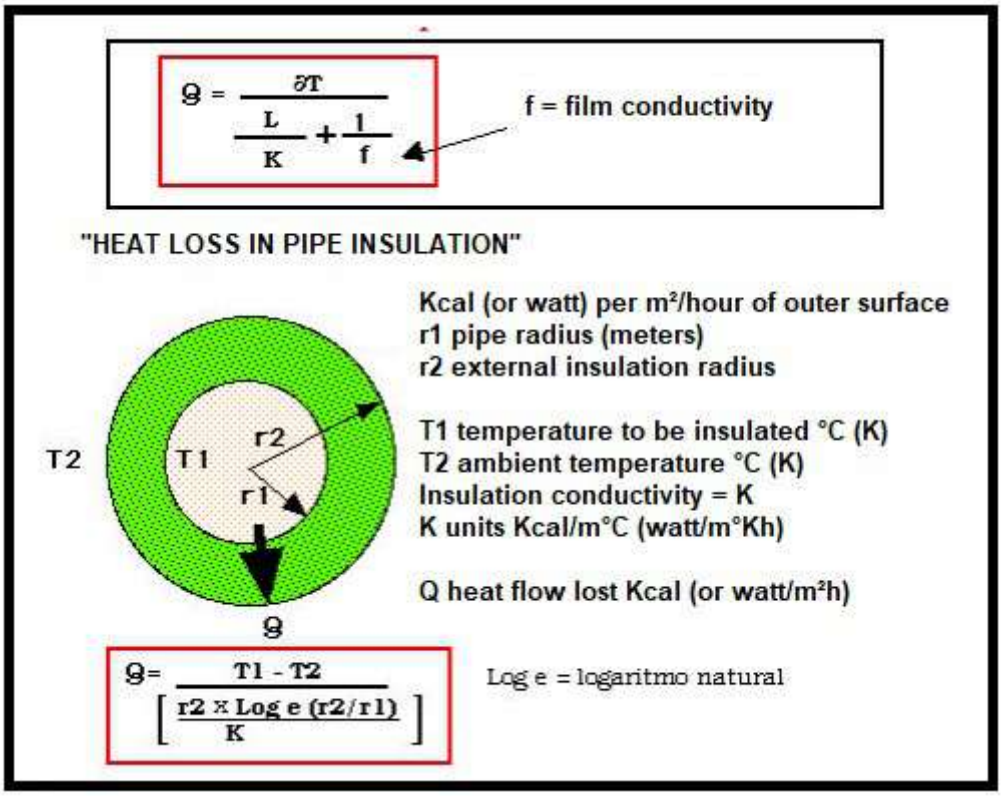
We must remember that insulating materials are limited to those that do not cause harm to people (such as asbestos, which can cause serious problems if inhaled, its use is prohibited).

The heat loss from a valve is equivalent to 1 meter of uninsulated pipe or 10 meters of insulated pipe of the same diameter.

The heat loss from a plate is equivalent to 0.3 meters of uninsulated pipe or 3 meters of insulated pipe of the same diameter.



Piping insulation heat loss is proportional to the temperature difference.


$Q = \frac{\partial T}{\frac{L}{K} + \frac{1}{f}}$
f = film conductivity
"HEAT LOSS IN PIPE INSULATION"
Kcal (or watt) per m²/hour of outer surface
r1 pipe radius (meters)
r2 external insulation radius
T1 temperature to be insulated °C (K)
T2 ambient temperature °C (K)
Insulation conductivity = K
K units Kcal/m°C (watt/m°Kh)
Q heat flow lost Kcal (or watt/m²h)
T2
T1
r2
r1
Q
$Q = \frac{T1 - T2}{\left[\frac{r2 \times \text{Log e}\,(r2/r1)}{K}\right]}$
Log e = logaritmo natural

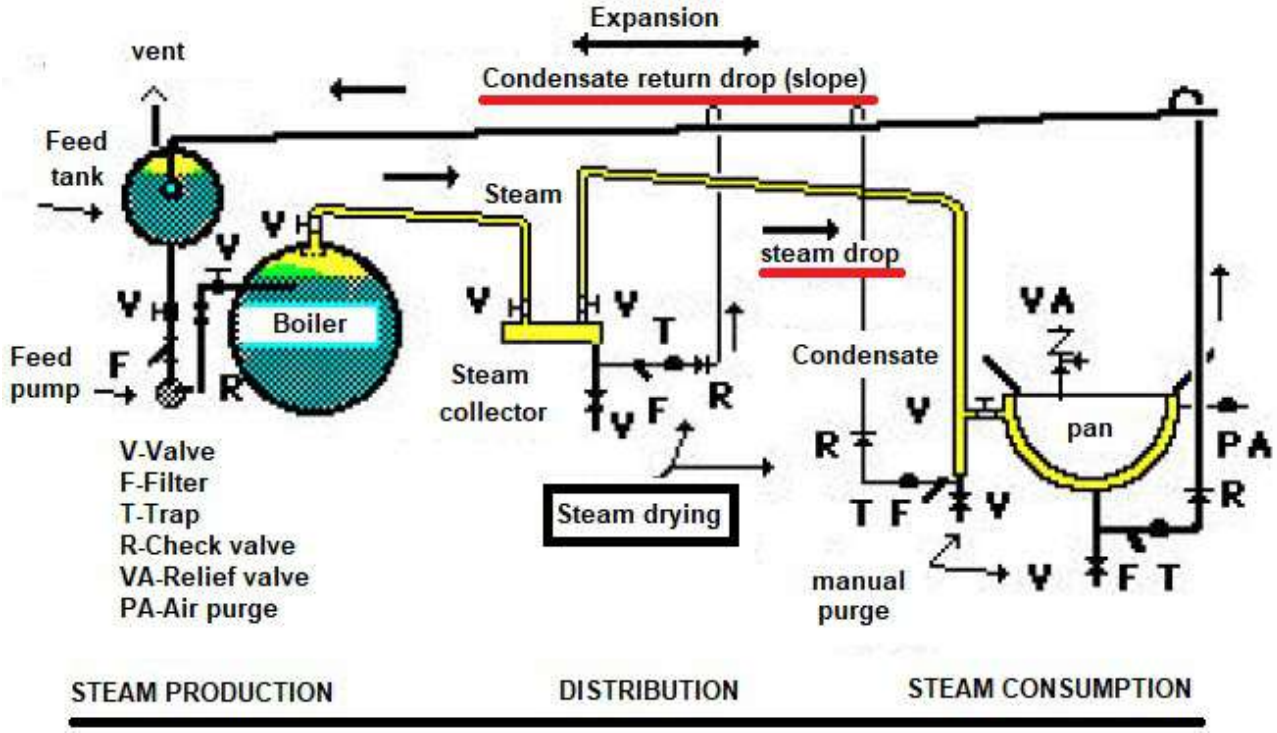
As we see in the previous table, the amount of heat Q is directly proportional to the temperature difference and inversely proportional to the thickness of the insulation and the K-value (a characteristic of each insulating material), and of course, also inversely proportional to its thickness.

There is a belief that "fiberglass" insulates better when it is "looser or lighter." This is a "myth," since what insulates is the "porosity" between the fibers.

Therefore, the smaller these pores, the less heat transfer occurs, as the air moves less; that is, the K-value increases with the density of the fiberglass.

The same applies, in a practical comparison, between a house made of concrete blocks and a house made of bricks (the latter insulates better).

The speed of the steam is between 15 m per second (54 km/h) in mild uses up to about 40 m per second (144 km/h) in uses where noise does not matter (there may be low pressure steams, i.e. close to absolute vacuum, which will be handled at more than 100 m per second, 360 km/h).



It is evident that the higher the steam velocity, the smaller the pipe diameter, but the greater the possibility of erosion, pressure loss, and noise that can be disruptive to people working nearby.

These velocities are what cause water hammer in the piping distribution.

Water has a significant density (weight per unit volume): 1 kg/dm³. If we imagine the mass of 1 liter of water (1 kg) at a speed of 100 km/h, stopped "instantly" against a metal wall, the energy it carries to reach that speed is released in fractions of a second, causing very large stresses.

Do not confuse "water hammer" with the knocking sounds produced by the "implosions" of the mixture of relatively cold water and "live steam" (in this case, "pops" are produced by the almost instantaneous condensation of the steam within the relatively colder water).To avoid "water hammer" and "pops" caused by water remaining in the lines, these should have a slope in the direction of steam flow (1 to 2%).

In each section that may condense due to cooling, a condensate removal system must be installed (manual drain with a "waste" bag, filter, steam trap, and retention or steam-condensate separators in areas where the steam is required to be "very dry," such as before regulating valves, steam atomizing burners, or in processes specifically designed for steam irons, etc.).

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In each section that may condense due to cooling, a condensate extraction system must be installed.

A complete installation includes: manual purge drain with a "waste bag," filter, steam trap, and steam and condensate separators or retention tanks in areas where the steam is required to be "very dry," such as before regulating valves, steam atomizing burners, or in processes specifically designed for use such as steam irons, etc.

All steam outlets (or steam intakes for the steam consumption points of the industrial plant) must exit from the top of the pipes to avoid carrying over condensate water. This condensate, by gravity, circulates in the lower part of the pipe. The goal is for only dry steam to reach the consumption points, without any liquid water carried over from the condensate in the steam distribution line.

In some cases (pipes with a diameter greater than 3 inches), it is advisable to install a gas trap at the top of the line, and always at the bottom (regardless of the pipe diameter) a condensate purge to prevent the permanent accumulation of condensate (which causes corrosion and can contaminate the steam with oxides).

The condensate lines should also slope in the direction of flow, and the secondary pipes should enter from the top (to minimize condensate backflow towards the points of consumption, although 45° check valves are also advisable). They should also be insulated to prevent heat loss.

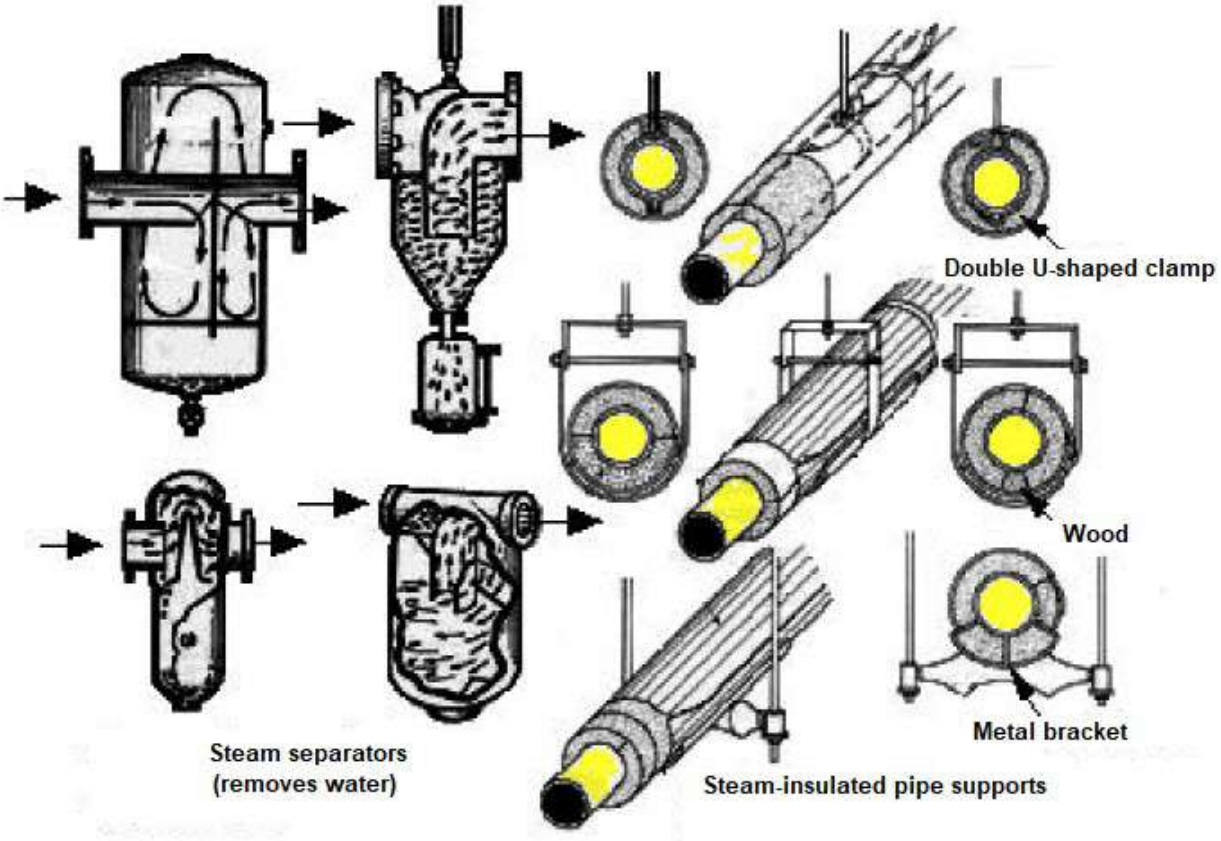
The gases produced by the decomposition of salts in the boiler's makeup water, as well as gases trapped within the boiler itself (due to contact with air or other gases, including condensate), are carried along with the steam produced in the boiler. These gases (which may be heavier or lighter than the steam) occupy space in the steam lines and heat exchangers, reducing their exchange capacity.

They cause corrosion and take up space that the steam needs to perform its heat exchange function. These gases must be removed to prevent these problems.

Heavy gases generally return along with the condensate (provided the traps are adequate for their removal) and must be extracted into the feed tank (venting) while maintaining the feedwater at a high temperature.

Light gases will not "fall" to exit the piping or heat exchanger, so they must be removed from the top using manual or automatic gas purges (thermal traps, thermodynamic traps, etc.).

A heat exchanger can lose more than 30% of its capacity if gas venting is inadequate.



ELEMENTS FOR STEAM DISTRIBUTION PIPES

Both steam and condensate pipes will expand (they lengthen when heated and contract back to their original size when cooled).

Therefore, we must study how to allow them to expand without creating stress or ruptures that could cause an accident.

If the pipes are not of a large diameter, they can be fitted with wide bends (avoiding elbows) in relatively short sections to allow for expansion without generating localized stress.

Otherwise, it will be necessary to install elements that absorb the expansion (expansion joints, Omega fittings, bellows, etc.).

Thermal expansion is approximately 1 mm per meter for every 100°C (212°F) increase in temperature. Therefore, only some of the pipes will be fixed, while others will be free to expand.

Care must be taken to ensure that the distances between supports do not create "sags" (downward curves due to the weight of the pipe). **These sags are low points in the pipe where condensate can accumulate and be carried away, causing a "water hammer" or "smacking" sound during commissioning.**

In any case, some supports will be fixed, while in others the pipe will be able to slide freely.

STEAM TRAPS

The use of steam for heating (steam as a heat source in industrial processes) can be done directly in some cases (heating water or water containing products that are not affected by the steam and its condensate).

Or indirectly: by preventing contact between the steam and water and the product being heated, and recovering the condensate.

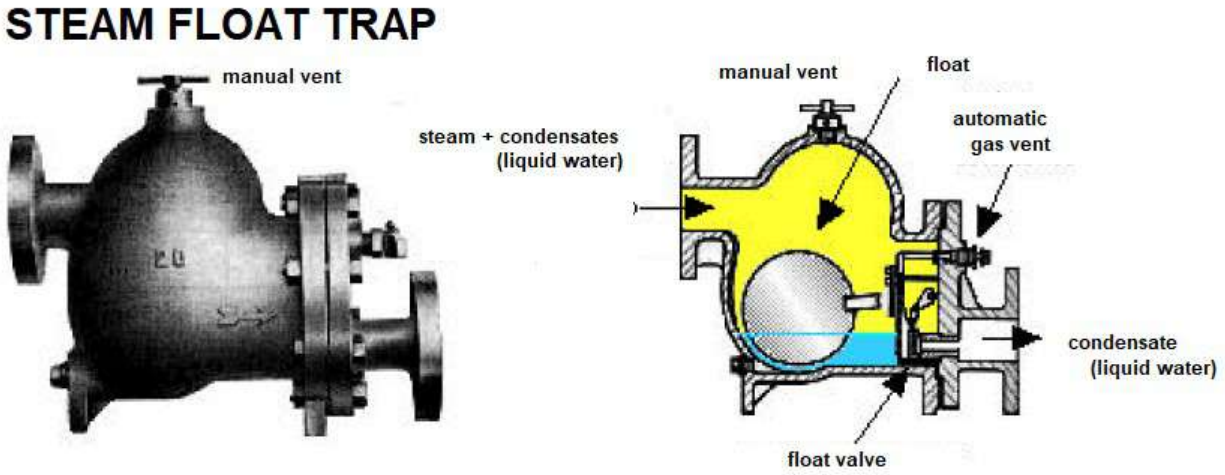
Condensate recovery plays a very important role in the quality of the feedwater: less makeup water, therefore less purge, better heat recovery, fewer chemicals, etc.

For indirect heating, we must ensure the efficient use of steam. Therefore, steam should not be allowed to escape from the heat exchanger until it has released its latent heat of vaporization, exiting the steam-consuming equipment as condensate.

For this purpose, we need steam traps.

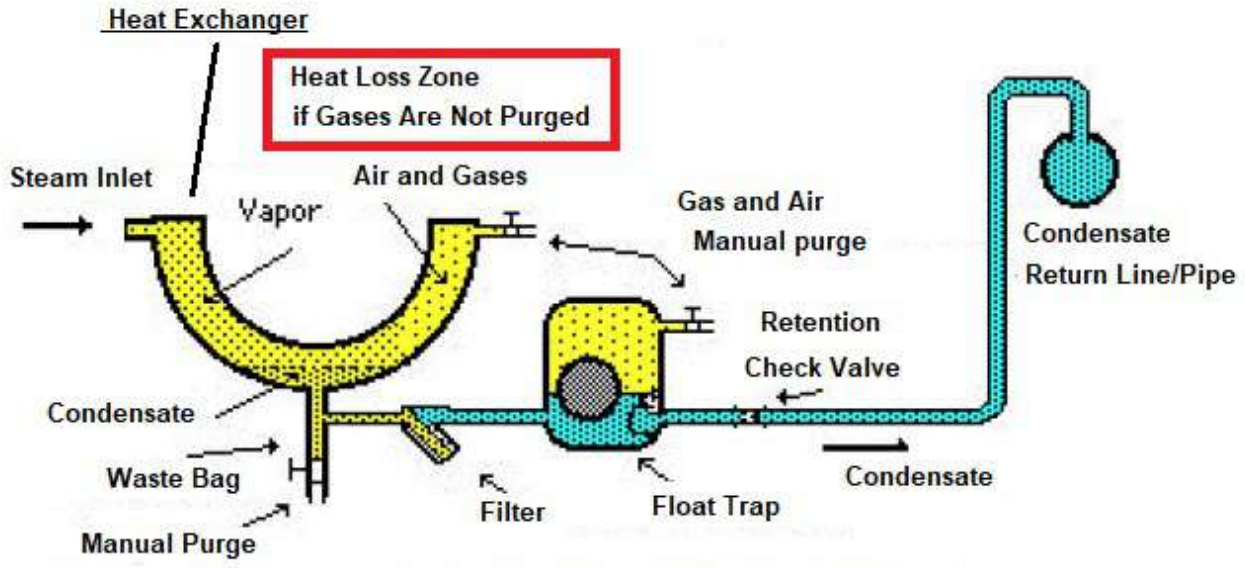
The function of the traps is to prevent steam from escaping and to drain the water that has condensed from the steam after it has released its heat.

The traps can operate in various ways or on several principles: the most basic would be the "float trap" (that is, a float or hollow sphere lighter than water and heavier than steam that rises as the water level rises and condenses. As it rises, it activates a valve that opens the outlet for this condensate, and once the condensate has escaped, as the level drops, the valve closes again).



This system needs an air or gas purge to prevent it from becoming "blocked" by trapped gases or air. This type of trap, the float trap, is ideal because it only allows the passage of condensate (whether superheated or not, i.e., above or below 100°C (212°F)), without consuming thermal energy to operate.

Other trap systems consume some form of energy to operate: normal bucket traps, inverted bucket traps, thermal traps, thermodynamic traps, etc., but they have other conditions that make them essential or desirable for certain uses.



Arrangement of Vapors, Gases, and Condensates in the Heat Exchanger

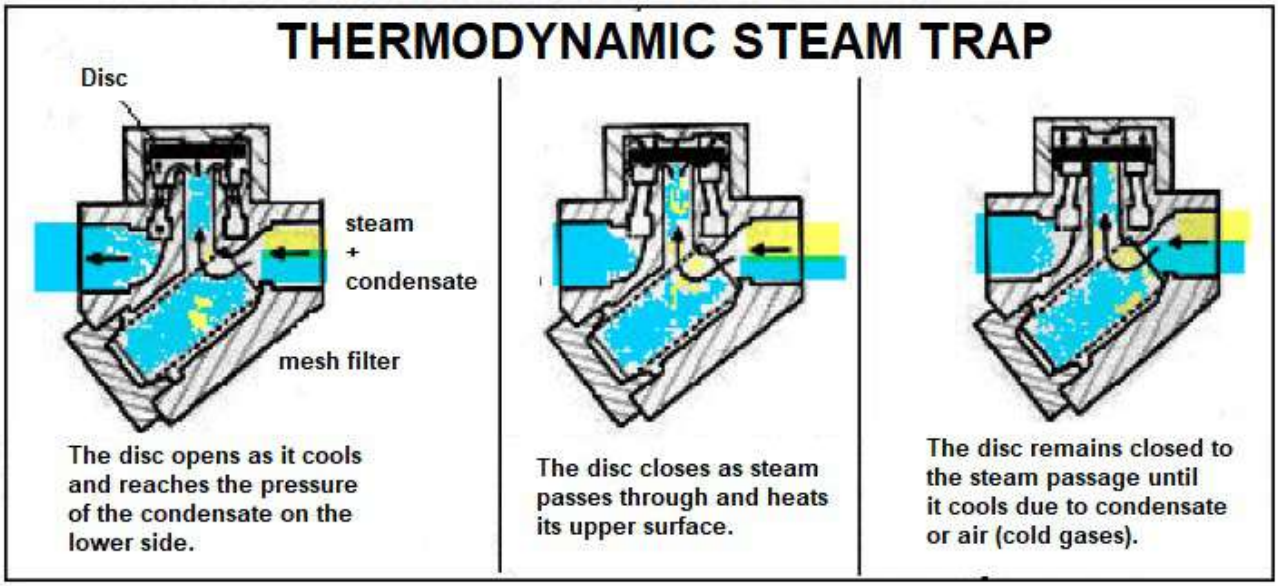
It is important to have the right steam trap for each use and condition; that is, each trap has a behavior that makes it better designed for certain applications or uses.

Large quantities of condensate, rapid or slower evacuations for subcooled condensate, high pressures, etc. And specific operating conditions (vapors contaminated with acids or alkalis, prevention of water hammer, superheated steam, etc.).

All steam traps must have a mesh filter at the inlet of the line steam, since condensate and steam carry hard materials from the pipes (metals, scale, etc.) that tend to scratch the valve seats of the traps, causing them to leak.

A leaking trap means that live steam can return through the condensate pipes without being used, and this loss can be quite significant in some cases.

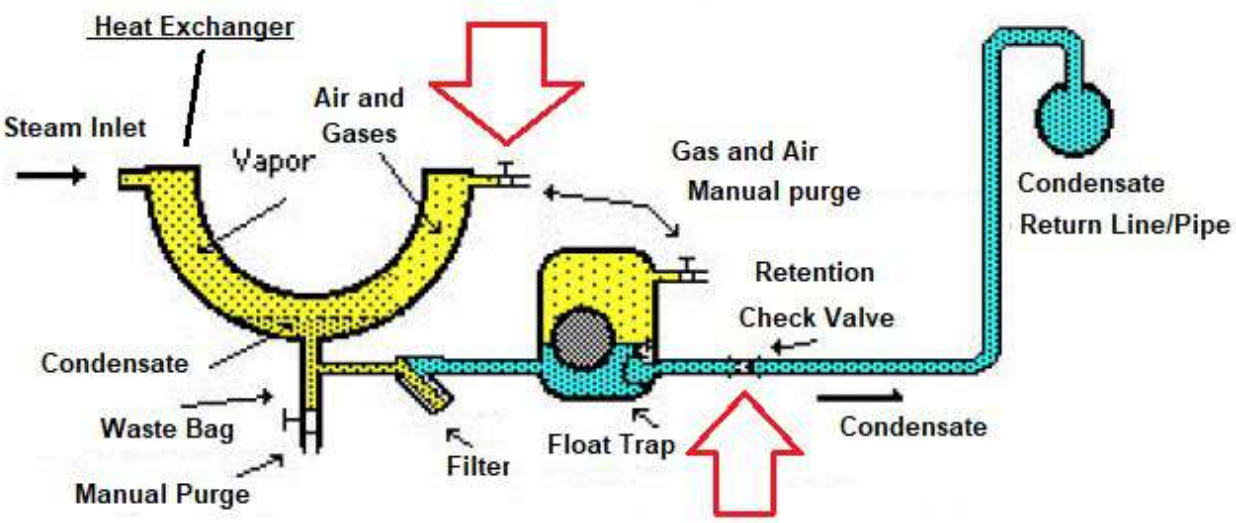
Some traps already have a filter built into their body, making an additional filter unnecessary. Pay attention to the metal used for the filter mesh; it must be stainless steel, otherwise it will corrode and become perforated quickly.


THERMODYNAMIC STEAM TRAP
Disc
steam
+
condensate
mesh filter
The disc opens as it cools and reaches the pressure of the condensate on the lower side.
The disc closes as steam passes through and heats its upper surface.
The disc remains closed to the steam passage until it cools due to condensate or air (cold gases).

It is good practice to install a manual drain valve before the steam trap, connecting it to a section of pipe that acts as a "waste trap." This means there should be a place where particles can settle and be periodically removed by gravity and the flow during draining, by purging the manual valve. The filters should be cleaned regularly.

Traps are not check valves, so in many cases it is advisable **to install a check valve to prevent condensate from flooding the heat exchanger** lines.

When shutting off the steam to the heat exchanger, be careful, as a partial vacuum may form inside. In some cases, this **vacuum must be broken by introducing air ("vacuum breaker") to prevent deformation** of the exchanger due to atmospheric pressure.



Whenever possible, prevent air from entering the condensate pipes, as the oxygen in the air accelerates the acidity of carbon dioxide (CO_2), leading to severe corrosion.

Some steam traps require condensate to be present inside them (bucket traps) to function. Therefore, we must be careful to use them in locations where condensate loss or backflow (from the trap itself) will not occur in the line and be replaced by steam or gases.

Choosing the right trap and designing the steam distribution and consumption system requires technical expertise that is often not found in textbooks.

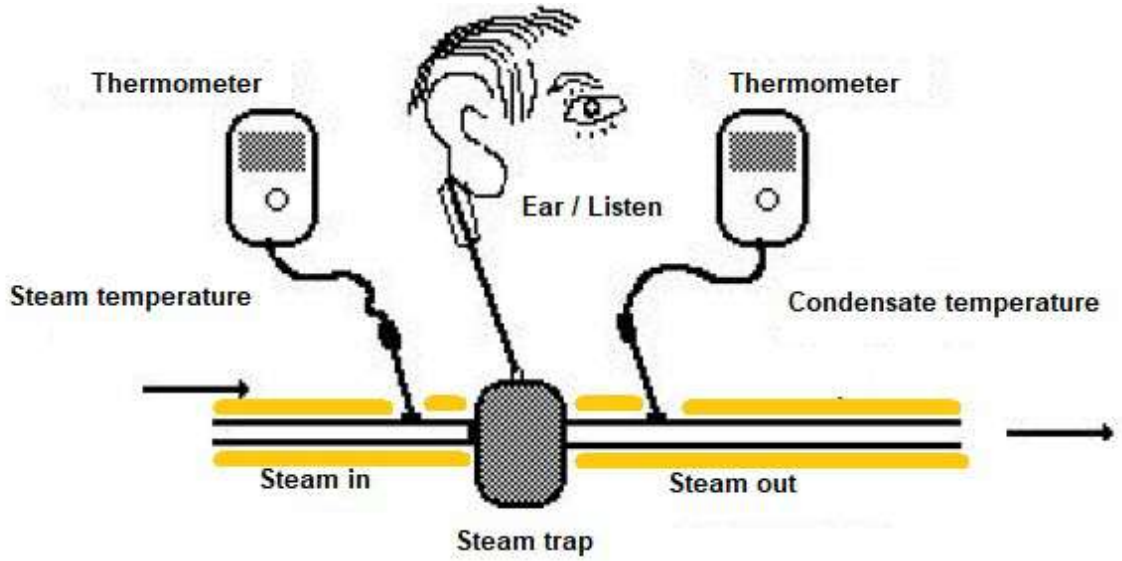
The installer must respect the slopes and bends in the pipes; these serve a purpose, they are not arbitrary or random, and are often key to proper operation.

Ensuring proper functioning and testing steam traps periodically is very important.

They can be tested by observing the steam circulating through an inspection window (which are not usually installed).

Or try using a screwdriver as a sound transmitter (or a mechanic's stethoscope). Depending on the type of trap, the noise can help us "suspect" it's malfunctioning. There are also "ultrasonic" devices that detect trap failures (i.e., the passage of live steam).

But a very interesting method is to measure the temperature on both sides of the trap. If the downstream temperature isn't significantly lower, it means live steam is passing through.



For example, if we're working at 10 kg/cm² (142 PSI), the temperature before the trap should be close to 180°C (356°F), and downstream of the trap it should drop about 40°C to 60°C (140°F), close to 100°C (212°F)).

All condensate discharged to a recovery system (feed or collection tank) must be at a higher pressure than the recovery system's pressure.

To achieve this, the steam temperature inside the heat exchanger (the steam consumption) must be at a value where the saturated steam pressure is higher than the pressure that must be overcome for discharge.

If the condensate temperature at the outlet to the recovery system is higher than the corresponding pressure of the recovery system, we say that we have superheated condensate.

Discharging at a lower pressure will cause evaporation until the temperature of the water and the resulting steam reaches the equilibrium temperature of saturated steam at the new recovery system pressure.

The fact that we have superheated condensate and that re-evaporation occurs after the traps (flash steam), if this re-evaporation is significant, will result in a substantial loss of heat that we will not be able to utilize. This must be studied to prevent it from happening.

Heat losses as FLASH STEAM

FLASH STEAM is produced because water leaves steam traps at the temperature of saturated steam or slightly lower (depending on the type of trap and installation or process), and when it comes into contact with a lower pressure, it re-evaporates (evaporates to the equilibrium pressure, taking heat from the superheated water, at the new saturation pressure, with the environment in which it is located, generally close to atmospheric pressure).

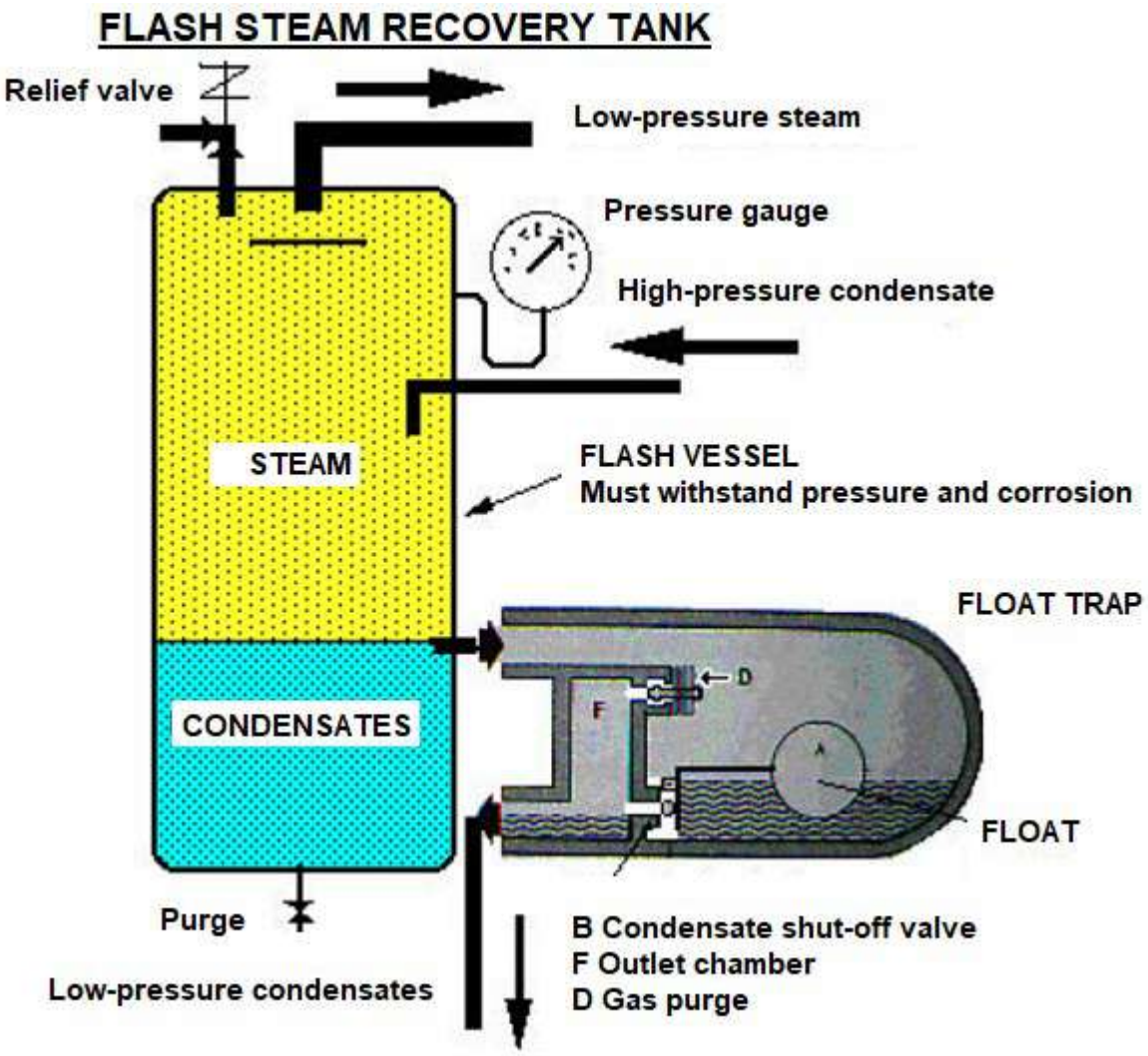
If this steam escapes into the atmosphere, it will be heat lost without being recovered, and with it, the water in the steam.

In other words, flash steam involves a double loss: the heat it carries and the water (condensed as steam, i.e., pure water).

Recovering FLASH STEAM can be as important as 15% or more of the energy produced.

There are several ways to prevent excessive flash steam production and various ways to reuse it in applications where the pressure (temperature) allows it.

Let's not forget that not only is energy lost, but also pure water (whenever possible, as much condensate as possible should be recovered).



In the previous figure, we have sketched a FLASH STEAM recovery tank.

Although there are other ways to utilize the heat from flash steam without using low-pressure steam, such as directly cooling the condensate and recovering the heat, or flashing the condensate under the boiler feedwater, utilizing the excess heat from the feedwater (in a water-to-water heat exchanger for plant use) or from water to air for heating in dryers.

The dimensions and the separation between the water and the steam are important (preventing entrainment with a separating diaphragm at the steam outlet).

Furthermore, it should be considered that the FLASH STEAM recovery tank, in the event of a system failure, can become pressurized to the boiler's operating pressure. **Therefore, it must have a good relief valve to limit its working pressure.**

It should also be considered that, due to the presence of condensate and corrosive gases, the construction material thickness must be sufficient to withstand corrosion and include a safety factor for overpressure (it is advisable to perform a hydraulic test at 1.5 times the high-pressure system).

The ideal trap is a float trap, leaving a water level inside the tank to maintain the internal equilibrium of the saturated steam. Thickness checks should then be performed in the lower section, especially during periods of fluctuating water levels, every few years of use.

Sometimes condensate recovery makes its use for boiler feedwater difficult due to cavitation of the feedwater pump caused by the high water temperature. The pump appears to have a "steam plug"; in reality, steam forms due to the high water temperature and the low suction pressure required.

This is corrected by positioning the feedwater tank at a sufficient height above the boiler feedwater pump (more than 4 to 5 meters above the pump) so that hydraulic pressure is generated, preventing re-evaporation (cavitation).

Some pumps are more prone to cavitation than others. These should be avoided, as draining the condensate and adding cold water is the worst possible solution in every sense.

The pump's suction piping is also important to prevent cavitation. A pipe with a small diameter, long length, elbows instead of bends, and a filter and valves with high pressure drop (generous filters and full-flow valves are needed) all contribute to pressure losses.

All of these factors add up to pressure losses that affect the pump's operation, causing cavitation due to the low suction required to overcome the pressure drop. This results in steam forming at the pump's suction.

Cavitation not only hinders water supply, but also causes pump failure due to mechanical corrosion, as the small bubbles collapse against the pump's metal, causing mechanical erosion that removes metal and promotes chemical attack, ultimately destroying the rotor diffusers (on the opposite side of the flow).

The height of the feed tank slightly affects condensate recovery by generating higher pressure at the discharge of the heat exchangers.

However, this is not usually a problem when operating at steam pressures above 1 kg/cm² (14 PSI). If this were to be an issue, it is preferable to install a low-pressure pump in a condensate recovery tank.

The tanks must be insulated and have bottom drains. **Never draw from the bottom of the tanks with the pumps to avoid pumping sediments (oxides, scale, sludge, etc.).**

The boiler's feedwater tanks must have adequate venting to release gases and air, which will be expelled when the tanks are heated by the return condensate.

If the condensate output is insufficient, it is advisable to install a heating pipe to heat the water to over 80°C, provided the tank's height above the pump allows it.

Homo-tubular boiler with 5 years of service, 365 days/year.
Classic internal chemical treatment, water softening.

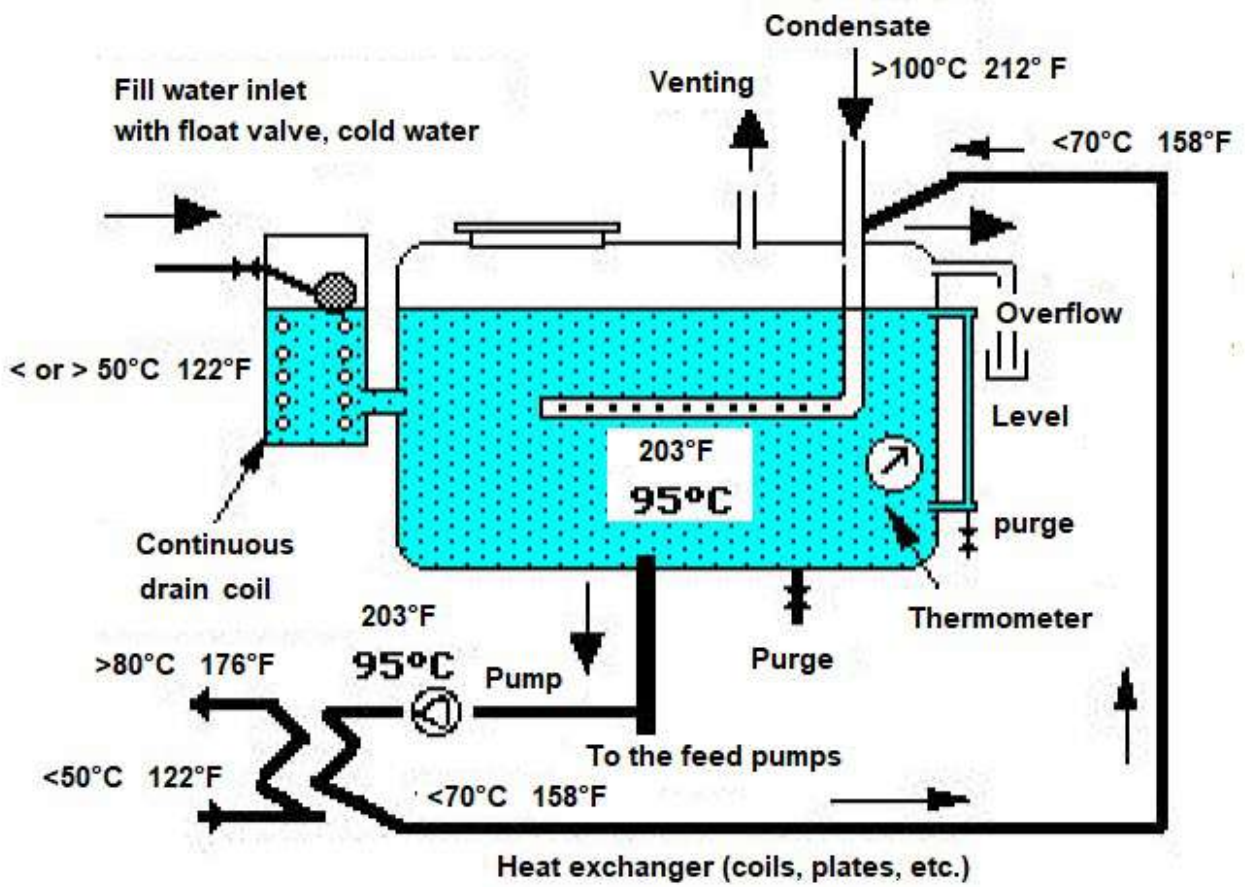
The following sketch shows a FEED TANK, incorporating some elements from our own experience (C.W.T. Carlos W. Thomasset experience):

1-Make-up water float outside the tank (to allow for repairs or maintenance while the system is running),

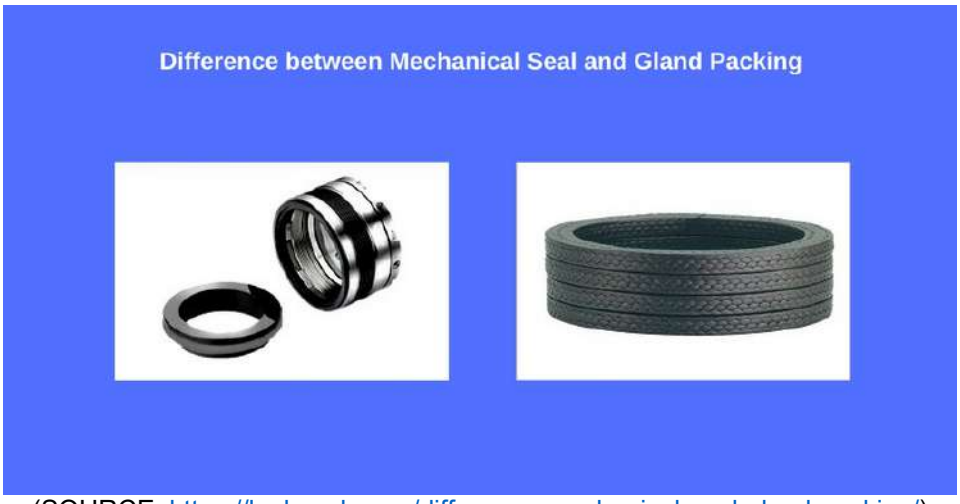
2-Continuous purge heat recovery coil in a cold zone (for greater heat recovery and to preheat the coldest water),

3-Condensate distributor under the feed water for flash steam recovery. Provided the tank water remains below 95°C (this requires cooling the feed water if it is overheated by the flash steam),

4-External heat exchange system for the feed tank water to utilize the excess heat from the flash steam (by heating water or air).



Feed pumps designed to operate at temperatures above 80°C (176°F) should ideally have **mechanical seals**, as **packing tends to overheat** due to friction and insufficient heat dissipation in very hot water. In this case, the pump packings should be externally cooled with cold water via a bronze ring through which the cold water circulates. This ring separates the packing into two sections, and its circular dimension is equal to that of a packing ring, providing internal circulation with water inlets and outlets.



(SOURCE: https://leakpack.com/difference-mechanical-seal-gland-packing/)

When operating equipment with "direct heating" (i.e., steam discharge directly into the water or water containing products to be heated: digesters, tanks, mixers, etc.**), it is advisable that the steam lines have a check valve, since shutting off the steam creates a partial vacuum that tends to draw in contaminated water**.

In the event of a power outage or accidental boiler shutdown (or steam shutoff), **contaminated water can travel through the steam lines to the boiler itself or, in combined systems with condensate recovery,** it can return as contaminated condensate produced by the "dirty" steam fed to the equipment when the steam system is restarted.

In the case of digesters, the situation is very serious, since they maintain internal pressure due to the temperature (balancing the feed pressure). When the boiler or system pressure decreases, they will tend to discharge through the steam supply pipe.

It is important that they have more than one check valve (of course, they must also have relief valves, regulated and limited steam pressure, etc.).

In all plants that are restarted, whenever they have been shut down for a period of time (more than a 6 or 8-hour shift), **it is advisable to drain the recovered condensate for a few minutes** to prevent potential contamination that could occur during shutdowns.

Therefore, it is necessary to install a valve that allows this recovered condensate to be drained before the condensate line reaches the feed tank.

Boiler water analyses generally indicate any contamination that may occur, allowing for measures to be taken, but it is more convenient to "prevent than cure" (to have elements and measures that avoid it).

Pressure regulators (devices that reduce steam pressure to a predetermined level) must operate free of condensate (their seats become scratched, and their calibrated orifices become perforated and clogged).

Therefore, it is necessary to install a **condensate separator with a condensate trap to dry the steam**.

It is also of paramount importance that they have **relief valves** capable of releasing all the overpressure generated in case the regulator valve ruptures when fully open (they generally tend to close).

If necessary, a **restriction (orifice plate)** should be installed with the valve **to limit the maximum steam** flow in case of rupture.

Choosing the right valve for each function and operating method: for example, **ball valves are excellent for quick closure, but should not be used to regulate flow** (the same applies to gate valves).

If flow regulation is required, a globe valve (or disc valve) should be installed, with a seat that allows for steam lamination.

Generally, in these cases, it is advisable to install two serial valves: **one for regulating**, connected to the steam utilization equipment, and **another for opening and closing**, connected to the steam supply, since the regulating valve will tend to leak steam as its seat deteriorates.

A well-planned and managed installation avoids many problems.

CHAPTER 9: EFFICIENCY IN BOILERS

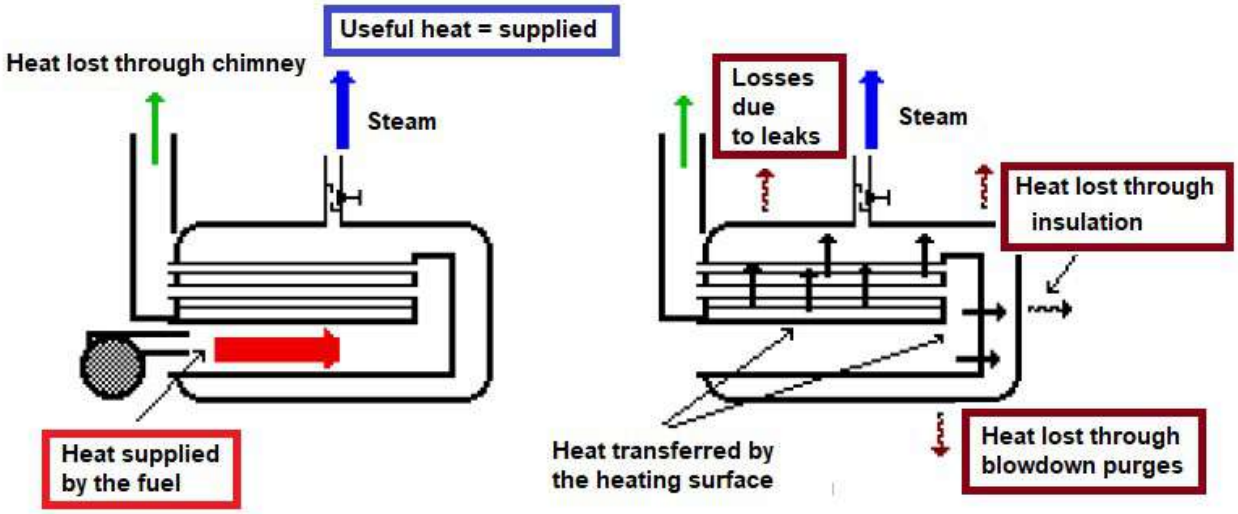
Measuring boiler efficiency means evaluating or measuring the percentage (%) of heat supplied by a fuel that is utilized.

This heat supplied by the fuel can be expressed as the Lower Heating Value (LHV) or the Higher Heating Value (HHV).

In boilers, we can broadly identify two types of heat loss:

One is caused by the **heat lost as hot gases exit through the chimney** (the air and fuel still present in these gases are considered to be at room temperature when used for combustion, although in some cases the fuel is heated by an external source such as electricity, but in practice, we will consider it as indicated at the beginning).

The second is the **heat loss caused by the boiler itself**, like any thermal equipment (heat losses through thermal insulation, water and steam losses, including necessary blowdowns, etc.).



Combustion efficiency:

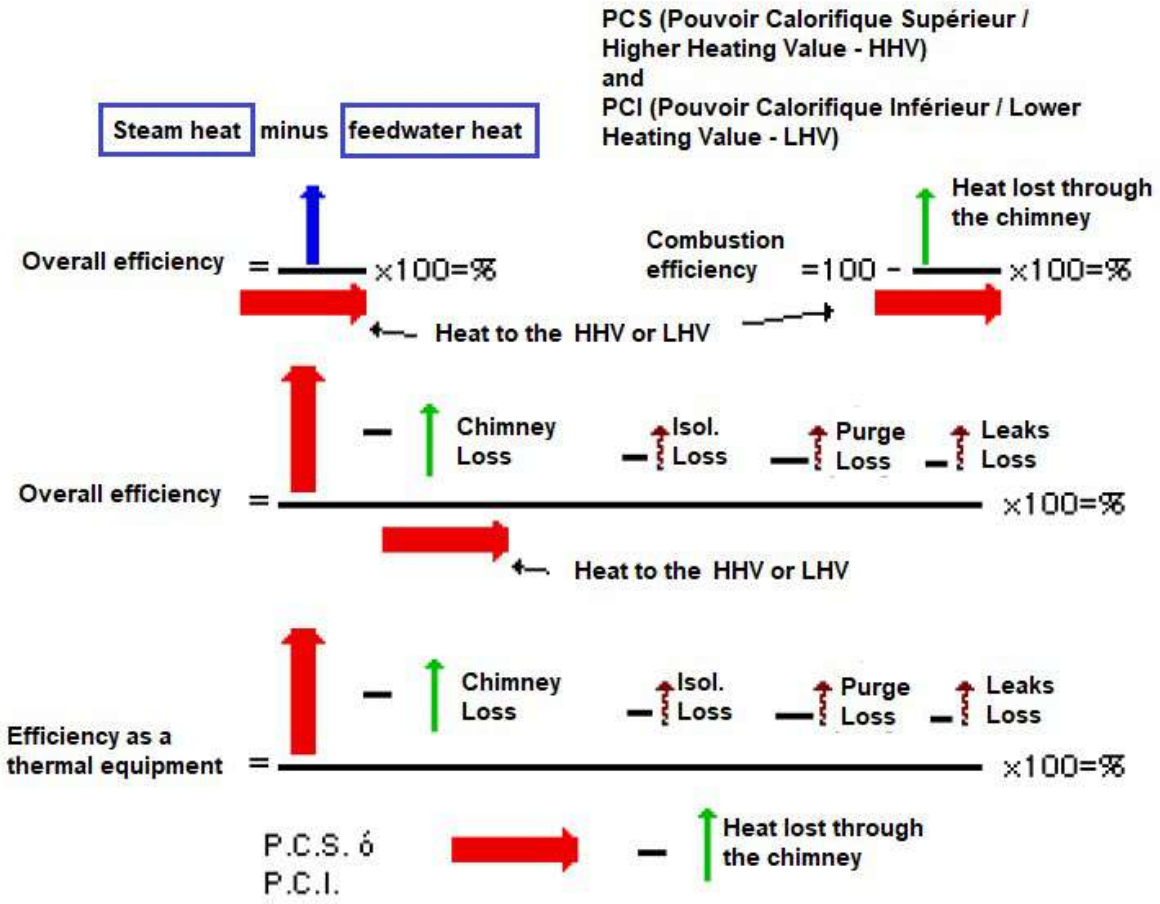
If we only consider the evaluation of the initial heat loss (through the flue gases), we can say that we are evaluating combustion efficiency: In this case, we are considering the heat that remained in the boiler, not the heat that is actually transferred to the steam.

By comparing measurements taken in the same boiler over a short period, we are actually comparing its combustion quality (excess air, unburned gases, etc.).

If we compare different boilers or the same boiler at different times, this combustion efficiency also takes into account the heat transfer conditions of the heating surface (soot buildup, scale on the water side, etc.) and direct losses to the outside (refractory lining, refractory casing, etc.).

It can also consider cases of internal ruptures in elements that direct hot gases to the heat exchange surfaces (baffles, diaphragms, vortices, etc.).

This is primarily noticeable by the increase in flue gas temperature. I believe this efficiency should be called **COMBUSTION AND HEAT TRANSFER EFFICIENCY.**



Boiler efficiency as a thermal equipment:

In this case, we are considering the percentage of heat supplied to the steam out of the total heat remaining in the boiler.

The heat remaining in the boiler is the percentage obtained from the calculation or measurement of combustion and transfer efficiency.

The heat supplied to the steam will be less due to heat losses through the boiler surfaces in contact with the boiler room air or through its structure. We must also add the losses caused by leaks of hot water and steam (taking into account necessary blowdown).

Boiler efficiency as a thermal equipment:

In this case, we are considering the percentage of heat supplied to the steam out of the total heat remaining in the boiler.

This efficiency, excluding steam and water losses (from blowdown), is fixed for a given pressure. Therefore, at higher vaporization rates, the percentage of heat transferred to the boiler will decrease.

For this reason, it is important that the boiler be designed for a normal operating rate of 70% to 80% of its capacity and that the water quality allows for minimal purge blowdown (maximum condensate recovery) and minimal steam losses with proper maintenance.

By considering combustion efficiency and the efficiency of the boiler as a thermal equipment, we can establish an overall efficiency.

The overall efficiency of a boiler is expressed as a percentage of the total heat supplied by the fuel (referred to the HHV or LHV) that is absorbed in the boiler and transferred by the steam.

To measure these efficiencies (combustion, boiler as a thermal equipment, or overall efficiency), we need to know or obtain a series of values that we will relate in mathematical expressions for each case.

These measurements will be taken with instruments (gas meters, thermometers, pressure gauges, flow meters, etc.) and values will be taken from tables (steam tables, Ostwald diagrams for gases, etc.).

Let's look at a practical way to perform these calculations, with an approximate value sufficient for normal evaluation work at low and medium pressure.

Boiler efficiency is established by two methods: Direct and Indirect.

Direct Efficiency (approximate):

Measure the amount of steam in kg/h (or the amount of feedwater less blowdown and losses in kg/h), its pressure, and its temperature, including the feedwater temperature.

At the same time, measure the amount of fuel consumed to produce this steam. From saturated steam tables, obtain the total heat of the steam (if unsaturated, use a superheated steam table) and the heat of the water at the feedwater temperature.

Using the following formula, you will obtain the approximate total efficiency directly:

$$\textit{Total Efficiency \%} = \frac{\textit{Kgs.steam/h x (Kcal/Kg. steam - Kcal/Kg. water) x 100}}{\textit{Kgs. fuel/h x Calorific power Kcal./Kg.}}$$

Indirect Efficiency (approximate):

In this case, chimney losses are measured, and by calculating their percentage, we can establish that:

100 - % losses in the flue gases = % Combustion efficiency (and transfer)

The losses from the boiler itself (blowdown, heat loss through its body to the room, water and steam losses) are not taken into account (since these are related to the Total Efficiency and not to the Combustion and Transfer Efficiency).

To calculate these chimney losses, we need to know:

Ai = Minimum theoretical air required by the fuel (kg/kg),

Ag = Water formed by the fuel + water from the fuel's moisture content (kg).

A% = Excess air (measured by CO2 or O2),
equal to (Excess air coefficient) x 100 - 100 = A% (see graphs in this chapter).

Cp = Specific heat of the combustion gases (approximately 0.25 kcal/kg).

This specific heat varies according to the composition of the gases and the operating temperature range (generally no less than 0.25 kcal/kg and no more than 0.26 kcal/kg).

T2 = Flue gas temperature in °C

T1 = Combustion air temperature in °C (room air temperature)

Heat value (HVL and LHV) of the fuel (kcal/kg)

$$\textit{Combustion efficiency HVL} = 100 - \frac{[(1+Ai \times (1+A\%/100) \times Cp \times (T2-T1) + Ag \times 600] \times 100}{HVL}$$

$$\textit{Comb.P.C.I. efficiency} = 100 - \frac{[(1+Ai \times (1+A\%/100)) \times Cp \times (T2-T1)] \times 100}{P.C.I.}$$

Note that in the combustion efficiency calculation related to the hottest part of the fuel, we have taken into account the heat absorbed by the water contained in the fuel as it evaporates (Ag x 600).

We have not taken into account the superheating of the water, the humidity of the air, or the unburned gases (since we are making a practical, approximate calculation).

Let's look at the minimum theoretical air quantity required, Ai, for common fuels:

Heavy Fuel Oil.....13.22 kg of air per kg of fuel oil

Super Gas.....15.7 kg of air per kg of super gas
Natural Gas.....16.3 kg of air per kg of natural gas

Firewood consumption varies with moisture content
(since higher moisture content means less fuel):

Firewood with 25% moisture.....4.8 kg of air per kg of firewood
Firewood with 30% moisture.....4.48 kg of air per kg of firewood
Firewood with 35% moisture.....4.16 kg of air per kg of firewood
Firewood with 0% moisture.....6.4 kg of air per kg of firewood

Rice husks with 10% moisture content.....4.36 kg of air per kg of husk.
Rice husks with 0% moisture content.....4.85 kg of air per kg of husk.

For the calculation of Ag x 600 we can substitute it with = P.C.S.- P.C.I. since the difference between them is the amount of heat in evaporating the total water (assuming that the fuel does not bring extra water after the analysis of the Heat Pump).

If we consider the Total Efficiency (which is equal to the heat delivered to the steam relative to the heat delivered by the fuel), we must consider the efficiency of the boiler as a thermal equipment (taking into account losses due to insulation, steam, water, and blowdown).

Since the boiler receives the heat we calculated in the Combustion and Transfer Efficiency (heat from the fuel - heat lost in the chimney) and delivers a smaller amount of heat to the steam due to these losses (insulation, blowdown, water and steam losses).

We can establish that:

Total Efficiency = Combustion Efficiency x Boiler Efficiency (as a Thermal Equipment).

With all efficiencies referring to the same calorific value (HHV or LHV), we can say that:

Total Direct Efficiency = Total Indirect Efficiency

Therefore, we can establish that the efficiency of the boiler as a thermal equipment is:

Boiler Efficiency (equipment) = Total Direct Efficiency ÷ Indirect Combustion Efficiency

The efficiency of a boiler as a thermal equipment, excluding blowdown and steam and water losses, is currently around 97% to 99% of the boiler's maximum output, thanks to the most compact and better-insulated modern boiler designs.

This means that the lower the boiler's steam output, the more significant this loss becomes. Therefore, boilers should be selected to operate at 70% of their steam production capacity, leaving 30% to handle momentary or transient loads.

Older boilers, with their extensive structure, refractory materials, and poor or inadequate insulation, had losses of around 10% to 15%.

This made them prime candidates for replacement with modern boilers (since these losses often represented the cost of a new boiler paid for in a single year).

Fuel Savings Calculation, Improving Combustion;

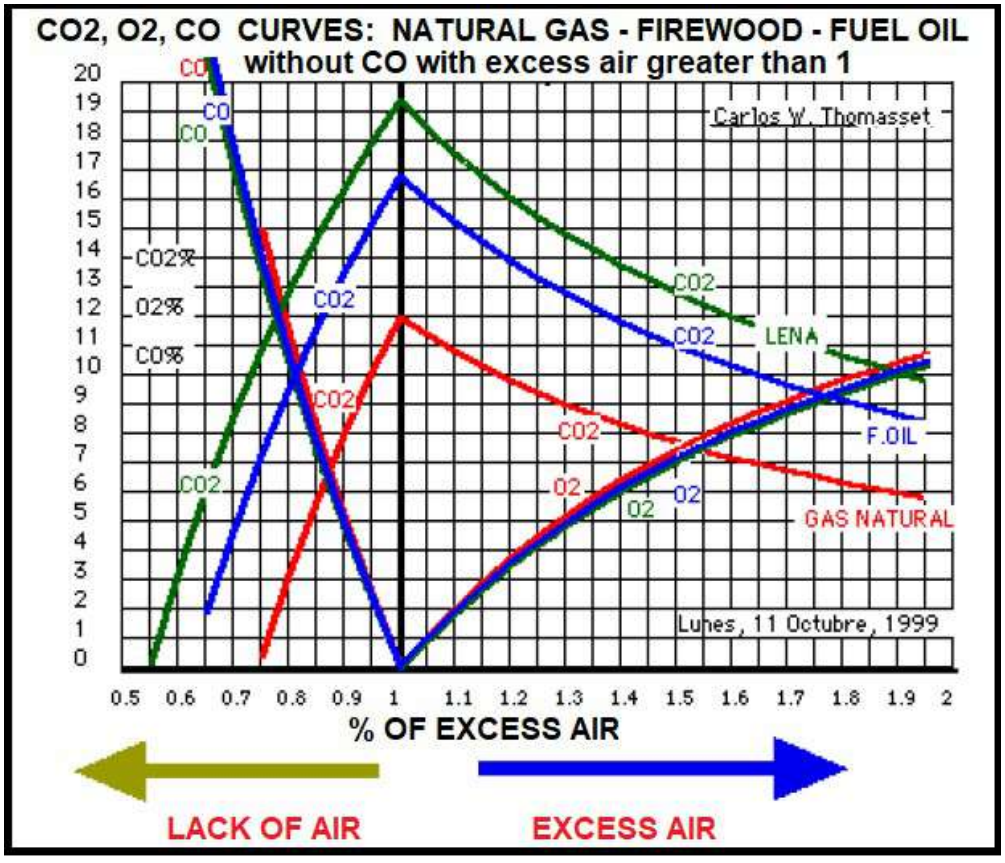
Assuming the boiler remains the same, its overall efficiency as a thermal equipment will remain unchanged. Fuel savings can be measured and calculated by measuring the combustion and heat transfer efficiency (by measuring excess air and using a thermometer):

$$\text{Savings \%} = \frac{[\text{Improved Combustion Efficiency \%} - \text{Previous Combustion Efficiency \%}] \times 100}{\text{Improved Combustion Efficiency \%}}$$

Fuel Savings Calculation, Reducing Blowdown and Leaks, and Improving Insulation:

$$\text{Savings \%} = \frac{[\text{Improved Total Efficiency \%} - \text{Previous Total Efficiency \%}] \times 100}{\text{Improved Total Efficiency \%}}$$

We have not taken into account unburned fuel in the form of ash, soot, etc.
Measuring Excess Air in Flue Gases:
To measure excess air in flue gases, we must use instruments and charts.
Not all excess air is due to air entering through the burner; there may be leaks through the boiler casing or inspection hatches. This air should be removed as much as possible by installing gaskets (or caulking cracks or openings that don't seal properly).

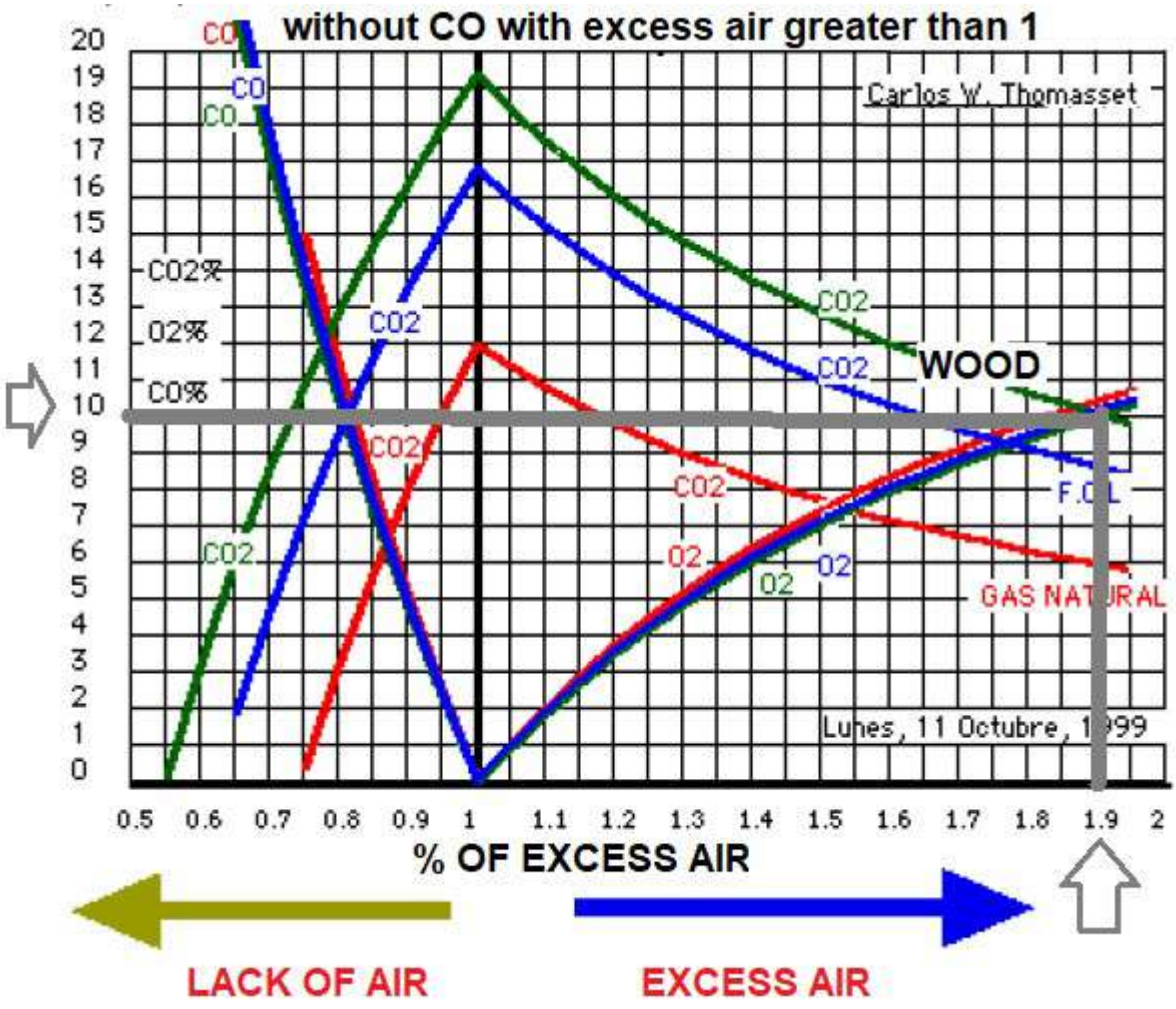


This graph provides an idea of the excess air coefficient when measuring chimney gases.

It has the drawback that it assumes there is no presence of CO (carbon monoxide, i.e., carbon that has "burned" with only one oxygen atom and released only 30% of its heat) when there is excess air.

Excess air begins at a value greater than 1, with the percentage excess being equal to the number minus 1 per 100.

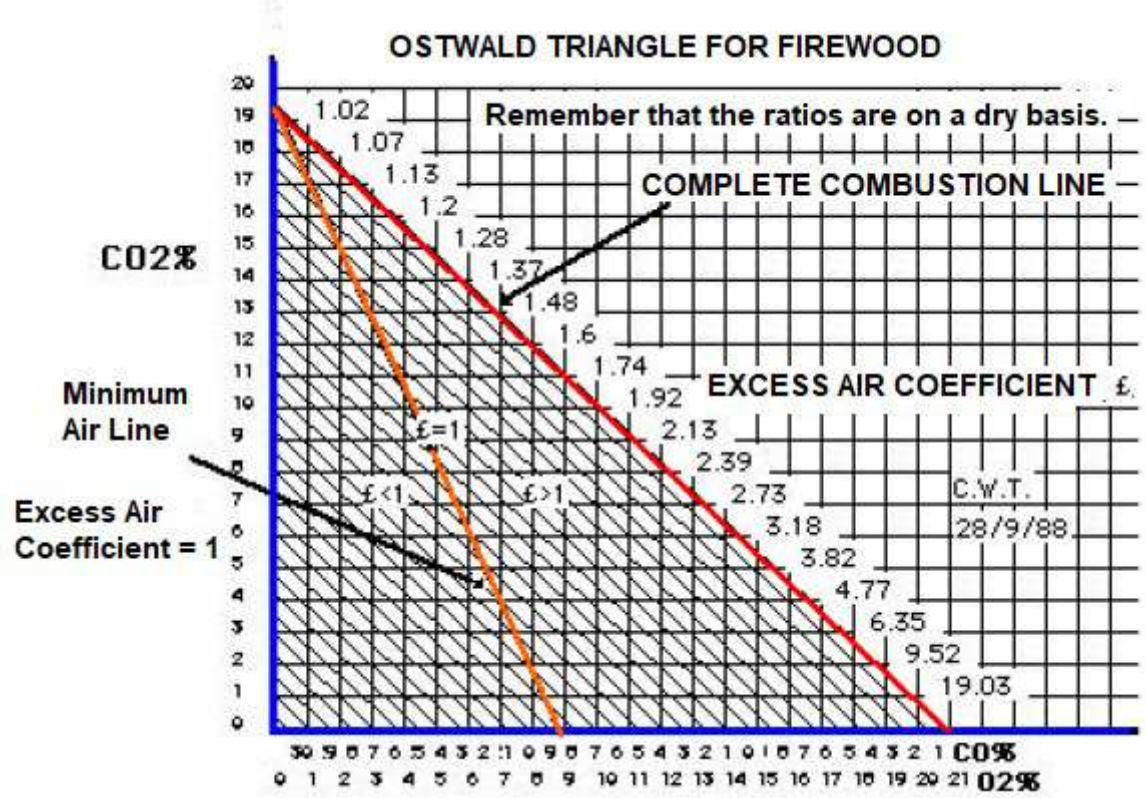
Example: measuring firewood, we have a CO2 of 10%. On the vertical axis, we read 10% CO2 and follow the horizontal axis
until it intersects the CO2 curve corresponding to the firewood. From that point, we go down the vertical axis to the horizontal axis where we read the Excess Air Coefficient 1.9. The percentage of excess air will be: 1.9 - 1 = 0.9 per 100 = 90% Excess Air.



In other words, we have 90% excess air, but with firewood, we typically need an excess of 40-50% air. Therefore, the actual excess air will be 90% - 40% (or 50%) = 40% (or 50%). **We must try to adjust the amount of air needed to avoid this high excess.**

We see that by measuring O2 (oxygen), the excess air is practically the same for the three fuels mentioned above for the same oxygen reading. Therefore, it is preferable to measure oxygen if possible, as it allows us to measure the excess air without knowing the exact composition of the fuel.

Since CO commonly appears in wood and gas due to poor combustion, it is preferable to use the OSTWALD triangle, for which we must always measure the CO2% or the O2%, but always measure the CO (which, even if there is excess air, can be produced by poor combustion).



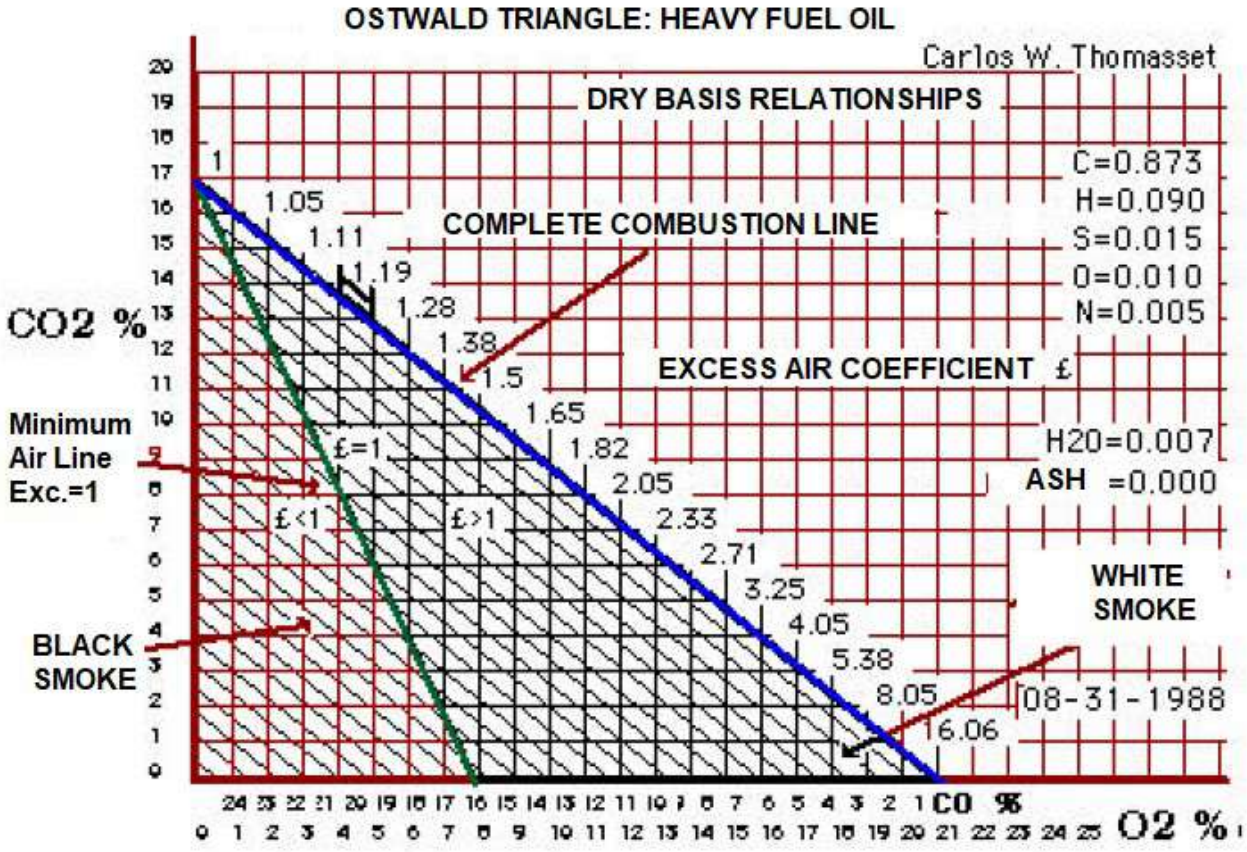
OSTWALD TRIANGLE FOR FIREWOOD

To use the Ostwald triangle for firewood, it is advisable to measure CO2 or O2 and CO in both cases (or all three is better: with an ORSAT, see Chapter 5 Part 7, 4 or 4a of 5).

The vertical line connects to the CO2 % readings, and the horizontal line connects to the O2 % readings in the lower numbering. If there is no CO, plotting the CO2 and O2 values will cause them to intersect at the hypotenuse, where the Excess Air Coefficient is read.

If we measure the CO% (which is advisable), we must read its value on the horizontal line corresponding to CO% and follow the lines parallel to the hypotenuse inside the triangle until they intersect at the point where they should join the lines for CO2% and O2%.

In this case, the Excess Air Coefficient must be obtained by drawing a line parallel to the line that marks the Excess Air Coefficient equal to 1 (minimum air required). This line would pass through the point of intersection of the lines (for CO2, O2, and CO) and would intersect the hypotenuse where the value of the Excess Air Coefficient would be read. (These lines were not drawn in this drawing to avoid obscuring the diagram).



OSTWALD TRIANGLE FOR HEAVY FUEL OIL

In plotting the Ostwald triangle, we assumed that CO is present only as unburned gas. However, in practice, when considering the presence of other unburned elements, such as hydrogen, we can estimate that we have the same amount of these unburned gases as the amount of CO.

In practice, normally if we measure with an ORSAT (CO2, CO and O2) it is very difficult for them to join at a point (100% theoretical point), so we have to

draw the triangle of the cuts between each of the lines (CO2 and CO, CO2 and O2, CO and O2) and take the midpoint equidistant from the 3 sides of this small triangle.

There may be significant differences between the ORSAT measurement and the Ostwald triangle we have, since the plot depends on the composition of the wood, its combustion, and measurement errors; however, its approximation is very useful for understanding combustion problems.

Calorific Values of Common Fuels:

HV (Higher Heating Value) LHV (Lower Heating Value)

The difference lies in the fact that the LHV subtracts the heat required to vaporize the water formed during hydrogen combustion and the water present as moisture in the fuel itself (LHV = HV - 600 x Total Water), while the HVV assumes the water is condensed (at 0°C), measuring all available heat.

Heavy Fuel Oil (Nº6)
P.C.S. =10300 Kcal./Kg. - P.C.I. = 9700 Kcal./Kg.
(HHV 18527 BTU/lb - 17448 LHV BTU/lb)

Super gas (bottles)
P.C.S. =12800 Kcal./Kg. - P.C.I. =11800 Kcal./Kg.
(HHV 23024 BTU/lb - 21225 LHV BTU/lb)

Natural gas
P.C.S. = 12290 Kcal/Kg. - P.C.I. = 11100 Kcal/Kg.
(HHV 22107 BTU/lb - 19966 LHV BTU/lb)

This value for natural gas corresponds to the Paysandú branch line (Uruguay, June 2000); the values should be taken from the information of the corresponding branch line (according to origin).

The volume of natural gas is generally expressed in cubic meters (m^3) at a temperature of 15°C and 1 atmosphere of pressure. Its specific gravity relative to air (approximately 0.62) or its weight per cubic meter (density) at a temperature of 15°C and 1 atmosphere of pressure (approximately 0.76 kg/m^3) allows us to establish a globular heat capacity (GHC) of 9,400 $kcal/m^3$ and a lower heating value (LHV) of 8,490 $kcal/m^3$ under the aforementioned pressure and temperature conditions.

These values vary according to the gas extraction zone and the gas treatment process.

Since firewood has different moisture levels, its calorific value will depend on the percentage of moisture in it, not only because of the water it forms and contains, but also because of the percentage of matter that is occupied by water (if the moisture is 40%, the dry matter will be 60% - with its water of formation - this water and 40% will be the water to evaporate).

Eucalyptus firewood:

Eucalyptus firewood, 0% moisture (completely dry)
P.C.S. = 4685 Kcal/Kg. P.C.I.= 4300 Kcal/Kg.
(HHV 8427 BTU/lb - 7735 LHV BTU/lb)

Eucalyptus firewood, 25% moisture
P.C.S. = 3510 Kcal/Kg. P.C.I.= 3080 Kcal/Kg.
(HHV 6314 BTU/lb - 5540 LHV BTU/lb)

Eucalyptus firewood, 30% moisture
P.C.S. = 3280 Kcal/Kg. P.C.I.= 2830 Kcal/Kg.
(HHV 5900 BTU/lb - 5090 LHV BTU/lb)

Eucalyptus firewood, 35% moisture
P.C.S. = 3045 Kcal/Kg. P.C.I.= 2590 Kcal/Kg.
(HHV 5477 BTU/lb - 4658 LHV BTU/lb)

Eucalyptus firewood, 41% moisture
P.C.S. = 2760 Kcal/Kg. P.C.I.= 2290 Kcal/Kg.
(HHV 4964 BTU/lb - 4119 LHV BTU/lb)

Rice Husk 10% moisture
P.C.S. = 3100 Kcal/Kg. P.C.I.= 2800 Kcal/Kg.
(HHV 5576 BTU/lb - 5036 LHV BTU/lb)

When firewood is cut in eucalyptus forests, its moisture content exceeds 60%.

The moisture content is given on a wet basis (% H w.b.).

That is, a quantity of **firewood is weighed ("Ph" Wet Weight), dried in a kiln at a low temperature (approximately 105°C, 221°F)** until it reaches a constant weight, and **then weighed again ("Ps" Dry Weight).**

The moisture percentage is calculated as follows:

% H b.w. = [(Ph - Ps) ÷ Ph] x 100

Be careful with the moisture content given on a dry basis (% H b.w.) (used by loggers, those who harvest and sell firewood), which is equal to:

% H b.w. = [(Ph - Ps) ÷ Ps] x 100

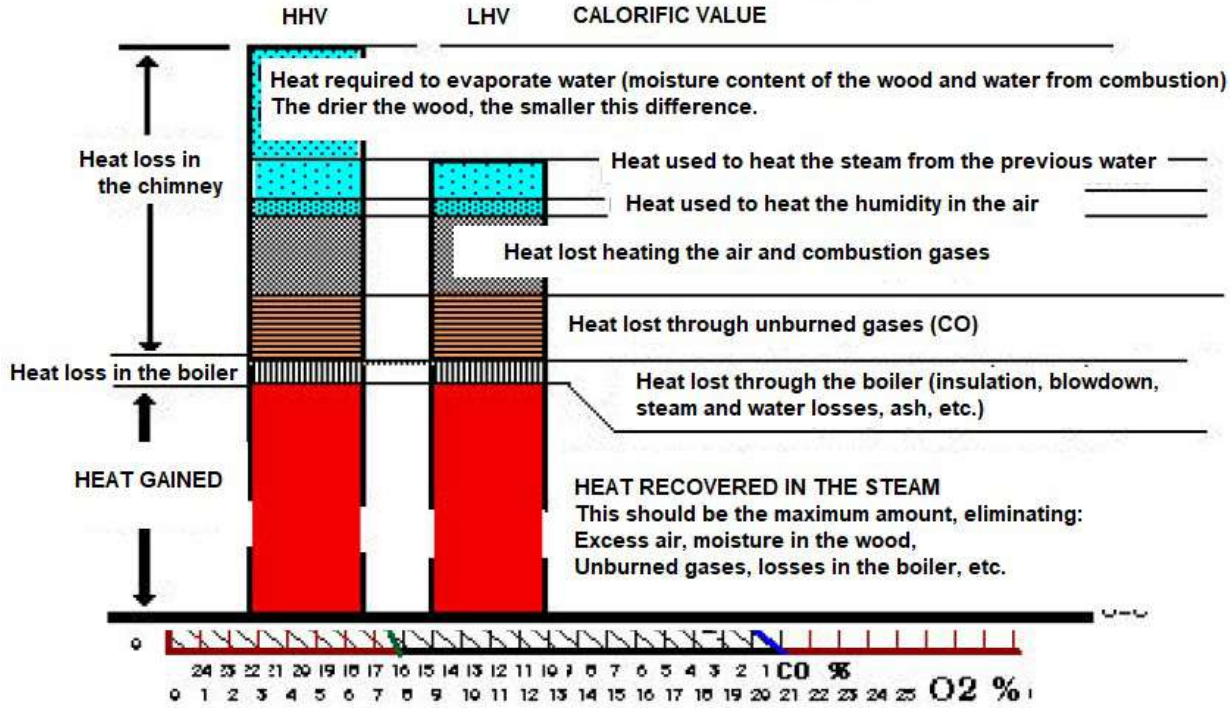
If we are given the moisture content on a dry basis (% H b.w.), we can convert from dry basis to wet basis:

% H b.w. = [% H b.w. ÷ (% H b.w. + 100)] x 100

Example: Firewood with a dry basis moisture content of % H b.d. = 25%. Applying the above, % H b.h. = 25 / (25 + 100) x 100 = 20% H b.h.

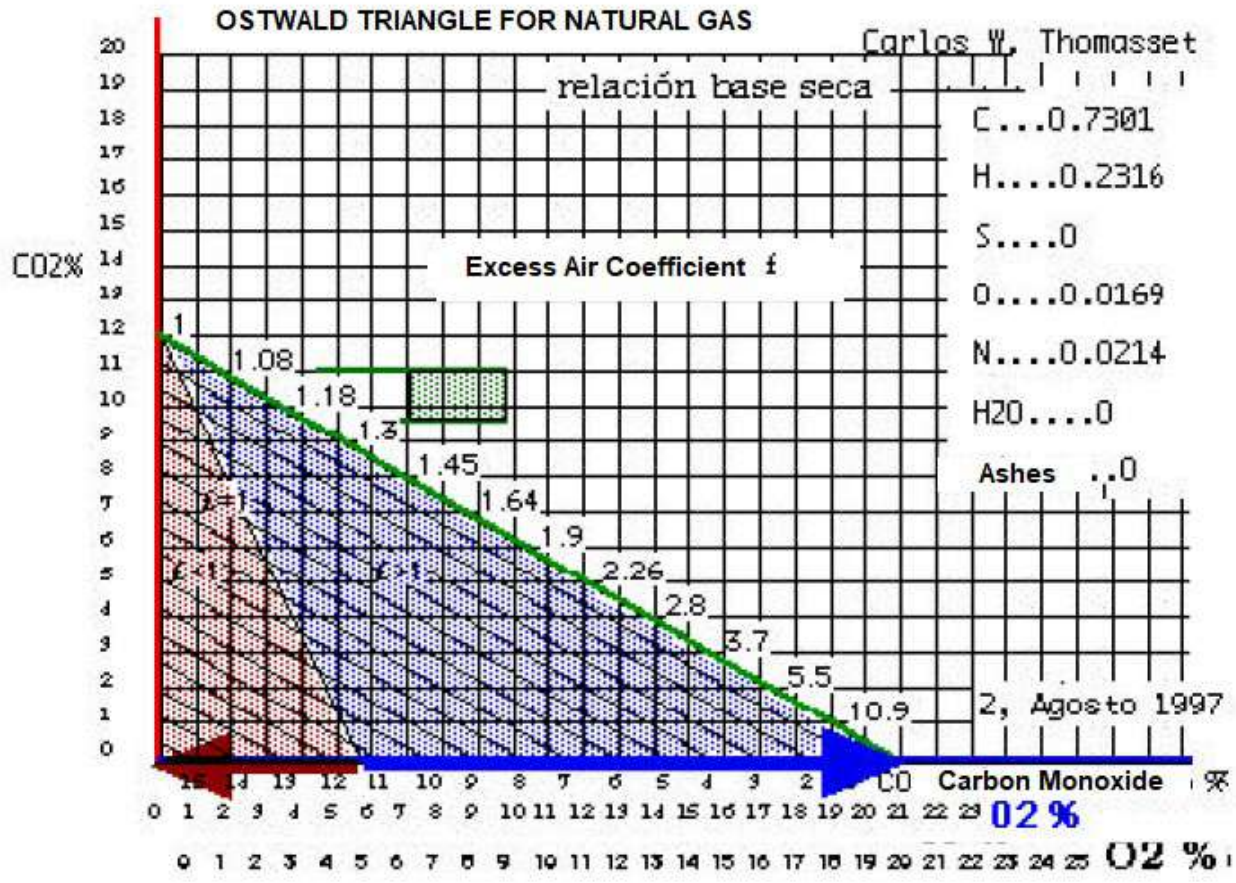
The two moisture values mean the same thing, but are expressed in different quantities. Therefore, it is necessary to clarify which basis (wet or dry) they refer to.

Comparative table when considering calorific values: higher and lower.


HHV
LHV
CALORIFIC VALUE
Heat required to evaporate water (moisture content of the wood and water from combustion)
The drier the wood, the smaller this difference.
Heat loss in the chimney
Heat used to heat the steam from the previous water
Heat used to heat the humidity in the air
Heat lost heating the air and combustion gases
Heat lost through unburned gases (CO)
Heat loss in the boiler
Heat lost through the boiler (insulation, blowdown, steam and water losses, ash, etc.)
HEAT GAINED
HEAT RECOVERED IN THE STEAM
This should be the maximum amount, eliminating:
Excess air, moisture in the wood,
Unburned gases, losses in the boiler, etc.
CO %
O2 %

Note that the absolute amount of heat utilized in the steam is the same in both cases; the percentage varies because the lower heating value (LHV) does not account for the heat of vaporization of the water (from humidity and combustion).

Apparently, the efficiency percentage at LHV is higher than that given with LHV, but when referred to the absolute heat utilized in the steam, it is the same. We see this in the case of wood.



Ostwald Triangle for Natural Gas

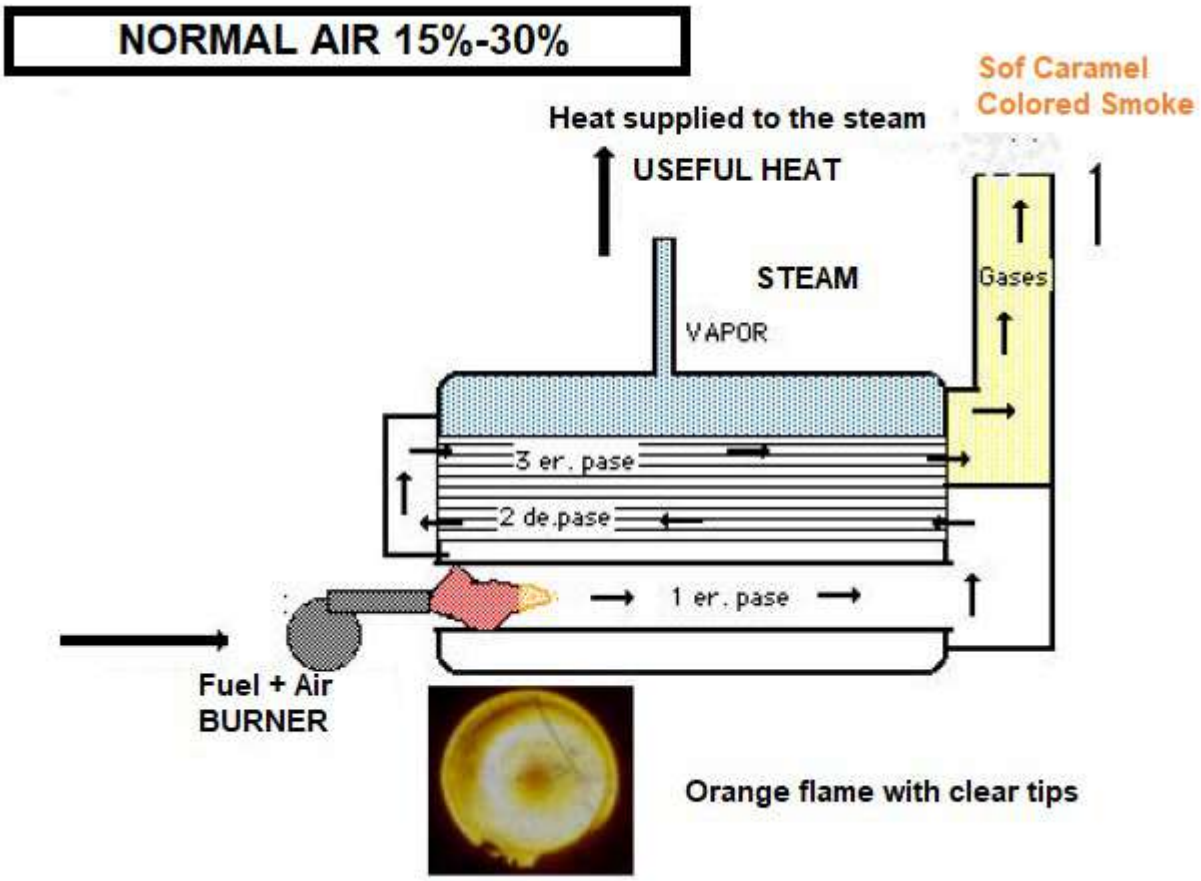
In summary: To improve each of the efficiencies studied, the following should be done:

<u>To improve combustion efficiency:</u>

Minimize the excess air required for combustion and air infiltration through joints or leaks in the boiler structure. Reduce losses from unburned gases by improving combustion conditions (atomization, fuel and air temperature, fuel-air mixture, fuel moisture, combustion temperature or zone where combustion occurs, etc.), and clean heat transfer surfaces.

Soot and ash are excellent insulators; chimneys and combustion chambers must be cleaned regularly.
Keep the water and steam side surfaces free of scale and insulating sludge by applying the appropriate chemical treatment.

Maximize the combustion chamber's heat transfer surface by adjusting the flame to the correct position for complete combustion, etc.



To improve the efficiency of the boiler as a thermal equipment:

in this case, we must find ways to prevent heat loss from the boiler to the boiler room through its insulation and structure, and prevent water or steam leaks (from valve stems, caps, pump packing, etc.).

We should also seek the best quality water to avoid high percentages of purge (blowdown), return as much condensate as possible, and perform proper internal chemical treatment. Alternatively, we should maximize continuous purge (blowdown) with heat recovery using heat exchangers.

Any of the above improvements will contribute to an improvement in overall efficiency.

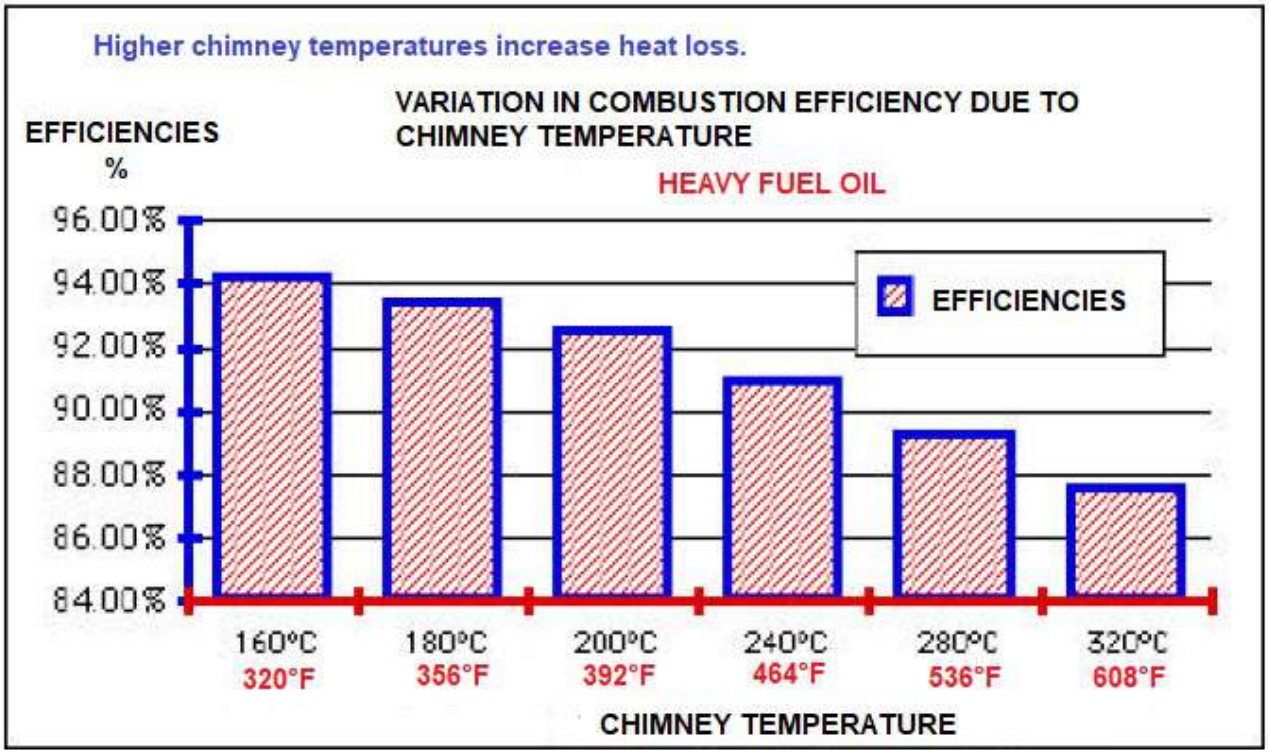
Remember to refer to efficiencies for the same calorific value (HHV or LHV), since although the quantities expressed as percentages are numerically different, their meaning when referring to each calorific value is not, thus preventing confusion in their numerical interpretation.

When expressing efficiencies, it is advisable to refer to the lower heating value (LHV). This allows us to more accurately judge the boiler's efficiency, as it largely eliminates the influence of fuel conditions (i.e., the hydrogen content that will form water and the moisture content).

In this way, we can compare boilers based on their individual efficiency, largely disregarding fuel quality.

When we express efficiencies in terms of the PCS (Percentage of Heat Used), we are taking into account fuel quality.

Therefore, when comparing boilers with PCS-measured efficiencies, we are actually comparing fuel quality rather than boiler quality, since the percentage differences are more noticeable due to the fuel than the boiler itself.



QUICK CALCULATION TABLES FOR COMBUSTION AND HEAT TRANSFER EFFICIENCIES (Calculated by the author)

The tables on the following pages allow you to calculate the COMBUSTION AND HEAT TRANSFER EFFICIENCY (LHV) from the CO2 or O2 measurement (if using the auxiliary ruler).

Remember that in this case, the tables correspond to CO2 measurements free of carbon monoxide (CO) or other unburned gases, i.e., complete combustion.

Since CO2 is generally the easiest to measure with a FYRITE or ORSAT, and the chimney temperature with a dial or electronic thermometer up to 500ºC (932°F) (placed in the chimney) and the ambient temperature with a common room thermometer.

The following tables are calculated for average fuels and in the case of firewood, the same with a wet basis moisture content of 25% (from 6 months to one year of seasoning, depending on the time of year, other values must be calculated).

Measure the CO2 content of the flue gases, the flue gas temperature, and the ambient temperature. Subtract the ambient temperature from the flue gas temperature (this will give the temperature difference, or the heat lost due to flue gas heating).

In the table provided (the right one of several shown in this chapter), enter the CO2 value on the left and the temperature difference at the top.

The intersection of the CO2 reading on the horizontal axis with the temperature reading on the vertical axis will give the COMBUSTION AND HEAT TRANSFER EFFICIENCY REFERRED TO THE LHV (Lower Heating Value).

To determine the excess air, refer to the CO2 or O2 curves, or the Ostwald triangles for each fuel, which are found in the book or in the auxiliary tables (following those related to the calculation).

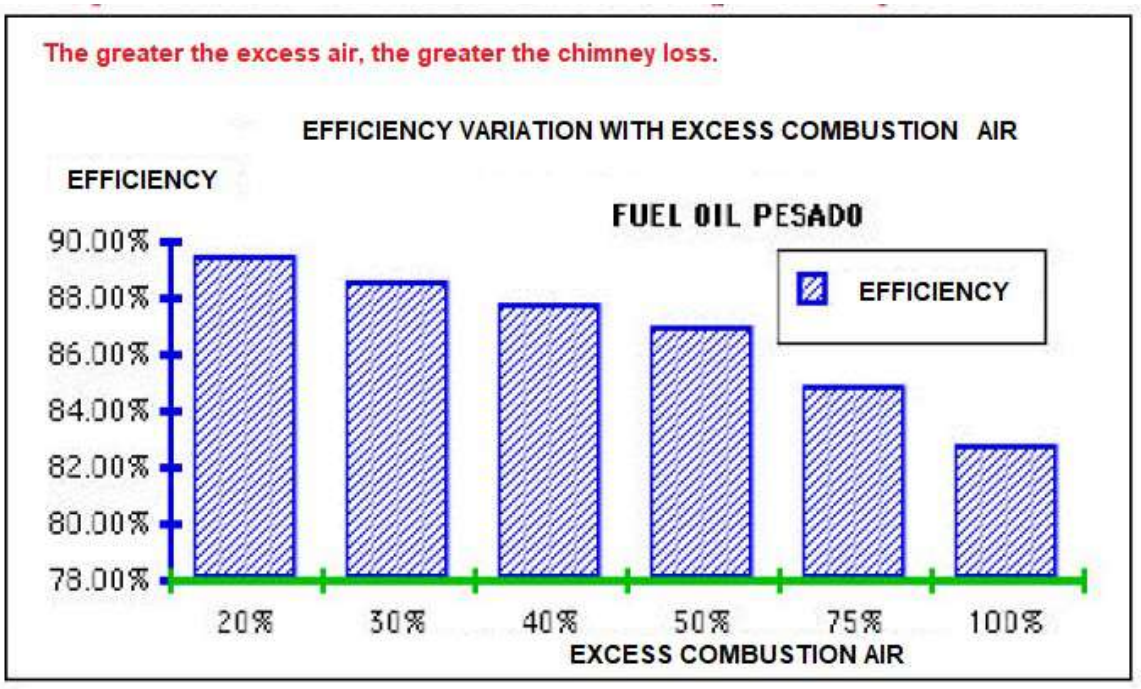
Printed on A4 hard paper/cardboard, the tables can be cut out (with scissors) to make up the EFFICIENCY RULES.

Using the corresponding tables for each fuel, cut out the appropriate space (indicated by dots) in the auxiliary tables.

You can then "fit" the corresponding table (for the same fuel) into the space below.

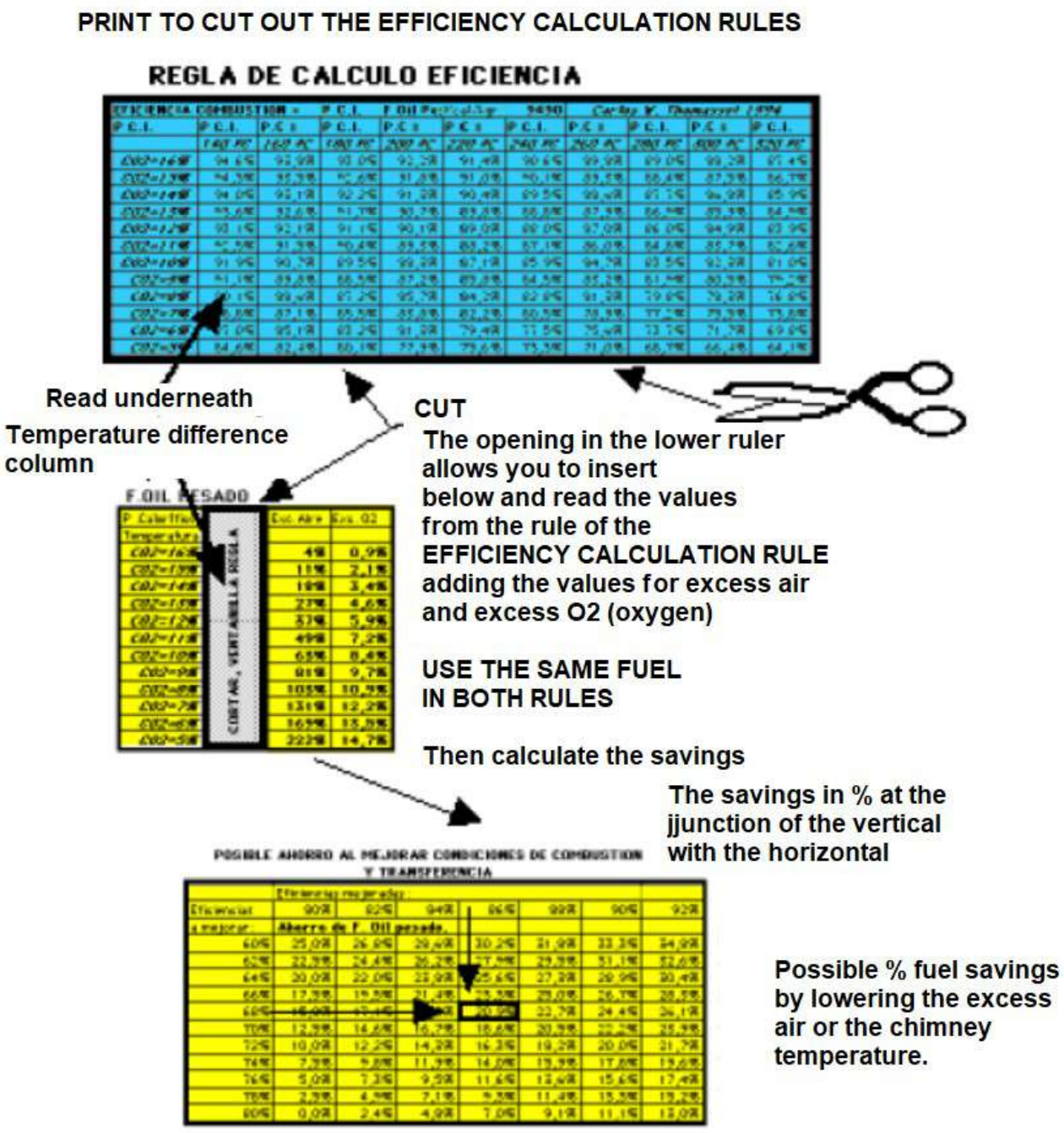
This will allow you to calculate the Combustion and Transfer Efficiency, as well as the excess air corresponding to each CO2 reading and the excess O2 (oxygen).

Alternatively, if you have an O2 meter instead of a CO2 meter, you can access each table.



Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 9: Efficiency in Boilers

PRINT TO CUT OUT THE EFFICIENCY CALCULATION RULES
Read underneath
Temperature difference column
CUT the opening in the lower ruler allows you to insert below and read the values from the rule of the EFFICIENCY CALCULATION RULE
adding the values for excess air and excess O2 (oxygen)
USE THE SAME FUEL IN BOTH RULES
Then calculate the savings
The savings in % at the junction of the vertical with the horizontal
Possible % fuel savings by lowering the excess air or the chimney temperature.


PRINT TO CUT OUT THE EFFICIENCY CALCULATION RULES
REGLA DE CALCULO EFICIENCIA
Read underneath
Temperature difference column
CUT
The opening in the lower ruler allows you to insert below and read the values from the rule of the EFFICIENCY CALCULATION RULE adding the values for excess air and excess O2 (oxygen)
USE THE SAME FUEL IN BOTH RULES
Then calculate the savings
The savings in % at the jjunction of the vertical with the horizontal
Possible % fuel savings by lowering the excess air or the chimney temperature.

GAS NATURAL P.C.I.

EFICIENCIA COMBUSTION =			P.C.I.	GasNatu	Kcal/kgr.	11500	Carlos W. Thomasset 1998			
P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.
	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2 =11,5%	94,3%	93,5%	92,6%	91,8%	90,9%	90,1%	89,2%	88,4%	87,5%	86,6%
CO2 =11,0%	94,1%	93,2%	92,4%	91,5%	90,6%	89,7%	88,9%	88,0%	87,1%	86,2%
CO2 =10,5%	93,9%	93,0%	92,1%	91,2%	90,3%	89,4%	88,4%	87,5%	86,6%	85,6%
CO2 =10,0%	93,6%	92,7%	91,8%	90,8%	89,9%	88,9%	88,0%	87,0%	86,0%	85,1%
CO2 =9,5%	93,4%	92,4%	91,4%	90,4%	89,4%	88,5%	87,5%	86,5%	85,5%	84,4%
CO2 =9,0%	93,1%	92,0%	91,0%	90,0%	89,0%	87,9%	86,9%	85,8%	84,8%	83,7%
CO2 =8,5%	92,7%	91,6%	90,6%	89,5%	88,4%	87,3%	86,3%	85,2%	84,1%	83,0%
CO2 =8,0%	92,3%	91,2%	90,1%	89,0%	87,8%	86,7%	85,5%	84,4%	83,2%	82,1%
CO2 =7,5%	91,9%	90,7%	89,5%	88,3%	87,1%	85,9%	84,7%	83,5%	82,3%	81,1%
CO2 =7,0%	91,4%	90,2%	88,9%	87,6%	86,4%	85,1%	83,8%	82,5%	81,2%	79,9%
CO2 =6,5%	90,8%	89,5%	88,2%	86,8%	85,5%	84,1%	82,7%	81,4%	80,0%	78,6%
CO2 =6,0%	90,2%	88,7%	87,3%	85,9%	84,4%	83,0%	81,5%	80,0%	78,5%	77,1%

LEÑA CON 25% H.b.h. P.C.I.

EFICIENCIA COMBUSTION P.C.I.=				Leña	Kcal/kgr.	3080	Carlos W. Thomasset 1991			
Humedad	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2=19%	92,6%	91,5%	90,4%	89,3%	88,1%	87,0%	85,9%	84,8%	83,6%	82,5%
CO2=18%	92,3%	91,1%	90,0%	88,8%	87,7%	86,5%	85,3%	84,2%	83,0%	81,8%
CO2=17%	91,9%	90,8%	89,6%	88,4%	87,2%	86,0%	84,7%	83,5%	82,3%	81,0%
CO2=16%	91,6%	90,3%	89,1%	87,8%	86,6%	85,3%	84,0%	82,8%	81,5%	80,2%
CO2=15%	91,2%	89,9%	88,6%	87,2%	85,9%	84,6%	83,3%	81,9%	80,6%	79,2%
CO2=14%	90,7%	89,3%	87,9%	86,6%	85,2%	83,8%	82,4%	81,0%	79,5%	78,1%
CO2=13%	90,1%	88,7%	87,2%	85,8%	84,3%	82,8%	81,3%	79,8%	78,3%	76,8%
CO2=12%	89,5%	88,0%	86,4%	84,9%	83,3%	81,7%	80,1%	78,6%	77,0%	75,4%
CO2=11%	88,7%	87,1%	85,4%	83,8%	82,1%	80,4%	78,7%	77,0%	75,3%	73,6%
CO2=10%	87,8%	86,0%	84,3%	82,5%	80,7%	78,8%	77,0%	75,2%	73,3%	71,5%
CO2=9%	86,7%	84,8%	82,8%	80,9%	78,9%	76,9%	74,9%	72,9%	70,9%	68,9%
CO2=8%	85,3%	83,2%	81,0%	78,9%	76,7%	74,5%	72,3%	70,1%	67,9%	65,7%

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F.Oil CALEFACCION P.C.I.

EFICIENCIA COMBUSTION =	P.C.I.	P.C.I.	P.C.I.	F.Oil Cal Kcal/kgr.	P.C.I.	10420	P.C.I.	Carlos W. Thomasset 1990	P.C.I.	P.C.I.	P.C.I.
P.C.I.	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2=15%	94,7%	93,9%	93,1%	92,3%	91,5%	90,7%	89,9%	89,1%	88,3%	87,5%
CO2=14%	94,3%	93,5%	92,7%	91,8%	91,0%	90,2%	89,3%	88,5%	87,6%	86,7%
CO2=13%	94,0%	93,1%	92,2%	91,3%	90,4%	89,5%	88,6%	87,7%	86,8%	85,9%
CO2=12%	93,5%	92,6%	91,6%	90,7%	89,7%	88,8%	87,8%	86,8%	85,9%	84,9%
CO2=11%	93,0%	92,0%	91,0%	90,0%	88,9%	87,9%	86,8%	85,8%	84,7%	83,7%
CO2=10%	92,4%	91,3%	90,2%	89,1%	88,0%	86,8%	85,7%	84,6%	83,4%	82,3%
CO2=9%	91,7%	90,4%	89,2%	88,0%	86,8%	85,5%	84,3%	83,0%	81,8%	80,5%
CO2=8%	90,7%	89,4%	88,0%	86,7%	85,3%	83,9%	82,5%	81,2%	79,8%	78,4%
CO2=7%	89,5%	88,0%	86,5%	84,9%	83,4%	81,8%	80,3%	78,7%	77,1%	75,6%
CO2=6%	87,9%	86,2%	84,4%	82,6%	80,9%	79,1%	77,3%	75,5%	73,7%	71,8%
CO2=5%	85,7%	83,6%	81,5%	79,4%	77,3%	75,2%	73,1%	70,9%	68,8%	66,6%
CO2=4%	82,3%	79,7%	77,2%	74,6%	72,0%	69,4%	66,7%	64,1%	61,5%	58,8%

F.Oil PesKoal/kgr. 9490

EFICIENCIA COMBUSTION =	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	Carlos W. Thomasset 1994	P.C.I.	P.C.I.	P.C.I.
P.C.I.	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2=16%	94,6%	93,8%	93,0%	92,2%	91,4%	90,6%	89,8%	89,0%	88,2%	87,4%
CO2=15%	94,3%	93,5%	92,6%	91,8%	91,0%	90,1%	89,3%	88,4%	87,5%	86,7%
CO2=14%	94,0%	93,1%	92,2%	91,3%	90,4%	89,5%	88,6%	87,7%	86,8%	85,9%
CO2=13%	93,6%	92,6%	91,7%	90,7%	89,8%	88,8%	87,9%	86,9%	85,9%	84,9%
CO2=12%	93,1%	92,1%	91,1%	90,1%	89,0%	88,0%	87,0%	86,0%	84,9%	83,9%
CO2=11%	92,5%	91,5%	90,4%	89,3%	88,2%	87,1%	86,0%	84,8%	83,7%	82,6%
CO2=10%	91,9%	90,7%	89,5%	88,3%	87,1%	85,9%	84,7%	83,5%	82,3%	81,0%
CO2=9%	91,1%	89,8%	88,5%	87,2%	85,8%	84,5%	83,2%	81,9%	80,5%	79,2%
CO2=8%	90,1%	88,6%	87,2%	85,7%	84,2%	82,8%	81,3%	79,8%	78,3%	76,8%
CO2=7%	88,8%	87,1%	85,5%	83,8%	82,2%	80,5%	78,9%	77,2%	75,5%	73,8%
CO2=6%	87,0%	85,1%	83,2%	81,3%	79,4%	77,5%	75,6%	73,7%	71,7%	69,8%
CO2=5%	84,6%	82,4%	80,1%	77,9%	75,6%	73,3%	71,0%	68,7%	66,4%	64,1%

HEAVY FUEL OIL - FIREWOOD - Heating Fuel Oil - NATURAL GAS

F.OIL PESADO

P .Calorífico / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2=16%		4%	0,9%
CO2=15%		11%	2,1%
CO2=14%		18%	3,4%
CO2=13%		27%	4,6%
CO2=12%		37%	5,9%
CO2=11%		49%	7,2%
CO2=10%		63%	8,4%
CO2=9%		81%	9,7%
CO2=8%		103%	10,9%
CO2=7%		131%	12,2%
CO2=6%		169%	13,5%
CO2=5%		222%	14,7%

LEÑA

Humedad / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2=19%		2%	0,4%
CO2=18%		8%	1,5%
CO2=17%		14%	2,6%
CO2=16%		21%	3,7%
CO2=15%		29%	4,8%
CO2=14%		38%	5,8%
CO2=13%		48%	6,9%
CO2=12%		60%	8,0%
CO2=11%		75%	9,1%
CO2=10%		92%	10,2%
CO2=9%		113%	11,3%
CO2=8%		140%	12,3%

F.OIL CALEFACCION

P .Calorífico / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2=15%		5%	1,0%
CO2=14%		12%	2,4%
CO2=13%		20%	3,7%
CO2=12%		30%	5,0%
CO2=11%		41%	6,4%
CO2=10%		54%	7,7%
CO2=9%		71%	9,0%
CO2=8%		91%	10,4%
CO2=7%		118%	11,7%
CO2=6%		153%	13,0%
CO2=5%		202%	14,3%
CO2=4%		276%	15,7%

GAS NATURAL

P .Calorífico / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2 =11,5%		4%	0,9%
CO2 =11,0%		8%	1,8%
CO2 =10,5%		13%	2,7%
CO2 =10,0%		18%	3,5%
CO2 =9,5%		24%	4,4%
CO2 =9,0%		30%	5,3%
CO2 =8,5%		37%	6,1%
CO2 =8,0%		45%	7,0%
CO2 =7,5%		54%	7,9%
CO2 =7,0%		64%	8,8%
CO2 =6,5%		76%	9,6%
CO2 =6,0%		90%	10,3%

Once the COMBUSTION EFFICIENCY and TRANSFER have been read, they can be compared to the efficiency of a more efficient boiler or to the improved flue values of the same boiler (reducing excess air or flue temperature, after soot or scale removal, or repairs to the internal gas distribution, etc., which improves heat transfer).

Using the following table (next page), enter the readings obtained in the left-hand column and then, finding the desired value in the top horizontal column, locate the corresponding savings at the intersection of both.

These savings allow us to compare boilers or the same boiler under optimal conditions.

POTENTIAL SAVINGS BY IMPROVING COMBUSTION AND TRANSFER CONDITIONS:

Efficiency to be improved (left vertical column)
Improved efficiencies (horizontal row)
>> Resulting % Fuel Savings

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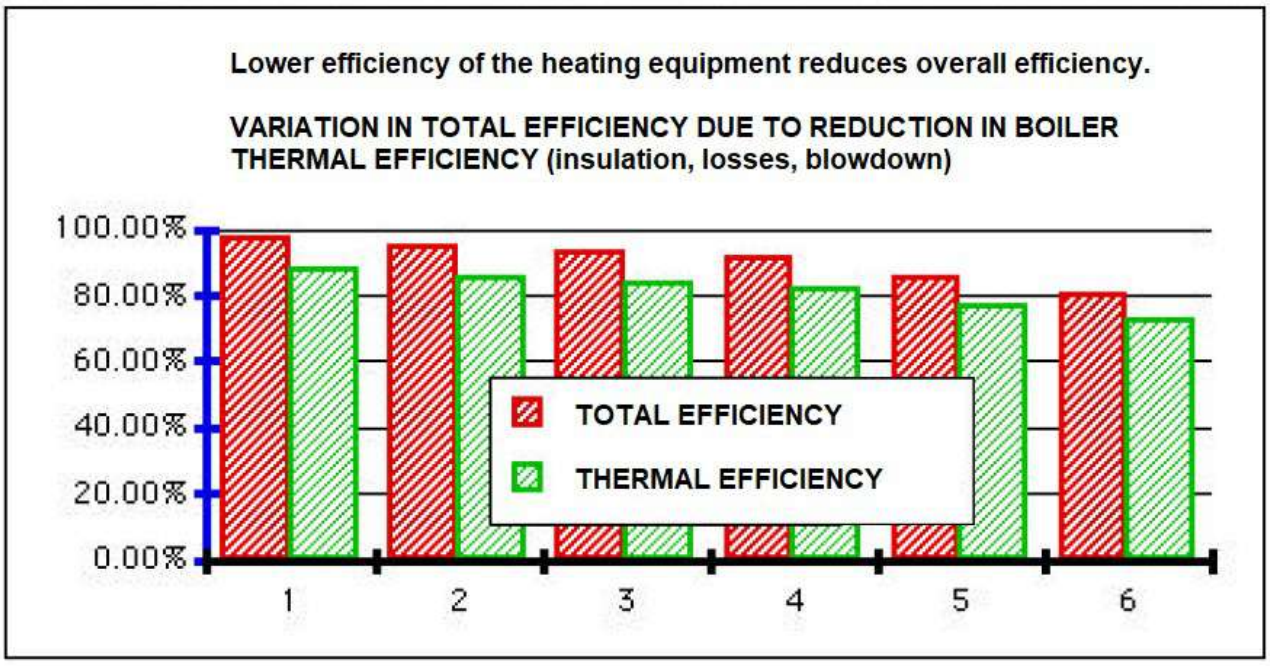
POSIBLE AHORRO AL MEJORAR CONDICIONES DE COMBUSTION Y TRANSFERENCIA

	Eficiencias mejoradas:						
Eficiencias	80%	82%	84%	86%	88%	90%	92%
a mejorar:	**Ahorro de combustible**						
60%	25,0%	26,8%	28,6%	30,2%	31,8%	33,3%	34,8%
62%	22,5%	24,4%	26,2%	27,9%	29,5%	31,1%	32,6%
64%	20,0%	22,0%	23,8%	25,6%	27,3%	28,9%	30,4%
66%	17,5%	19,5%	21,4%	23,3%	25,0%	26,7%	28,3%
68%	15,0%	17,1%	19,0%	20,9%	22,7%	24,4%	26,1%
70%	12,5%	14,6%	16,7%	18,6%	20,5%	22,2%	23,9%
72%	10,0%	12,2%	14,3%	16,3%	18,2%	20,0%	21,7%
74%	7,5%	9,8%	11,9%	14,0%	15,9%	17,8%	19,6%
76%	5,0%	7,3%	9,5%	11,6%	13,6%	15,6%	17,4%
78%	2,5%	4,9%	7,1%	9,3%	11,4%	13,3%	15,2%
80%	0,0%	2,4%	4,8%	7,0%	9,1%	11,1%	13,0%



Photograph with our beloved father Carlos Walter Thomasset
A man who did everything in life thinking of others
—family, friends, acquaintances, Uruguay society
—and not for his own.

CHAPTER 10: ELECTRICITY IN THE BOILER

10- ELECTRICITY APPLIED TO THE BOILER

Automatic controls, alarms, water feed pumps, fuel pumps, fans (forced and induced draft), etc., are normally (nowadays) based on the use of electricity.

In the past, boilers used steam power and human control.

Electricity can be defined as the use of the phenomena caused by the flow of electrons in conductive and semiconducting materials.

There are materials through which electricity flows: Conductors (gold, silver, copper, aluminum, iron—that is, almost all metals, as well as water containing ionizing salts, etc.)

They are used to transport electricity and harness its power: conductors or electrical cables.

Materials in which electricity flows with difficulty are: Semiconductors (metalloids or materials that barely conduct electrons due to impurities of other materials: silicon, germanium, etc. They are used in electronics to manufacture transistors, diodes, "chips", etc.).

Those through which electrons do not flow are: Insulators (they do not allow the passage of electrons; they serve to "isolate" or prevent the "loss or escape" of electrons from the materials that conduct them: the "sheathing" of cables, insulating tape, plastics, micarta, insulating varnish, dry wood, etc.).

Voltage (potential difference): This is the force with which these electrons are "propelled" (just as the height of a water tank above a tap determines the "pressure" or "force" with which the water flows).

It is measured with a voltmeter, and the unit used is the volt. Amperage (current or intensity): This is the "amount of electricity or electrons" that passes through a conductor in a given time (just as if we were measuring the liters per second of water flowing from a tap). It is measured with an ammeter, and its unit is the ampere.

Multiplying the two previous values gives the result of power, which is measured in watts (w) or kilowatts (kW = 1000 watts). This gives us an idea

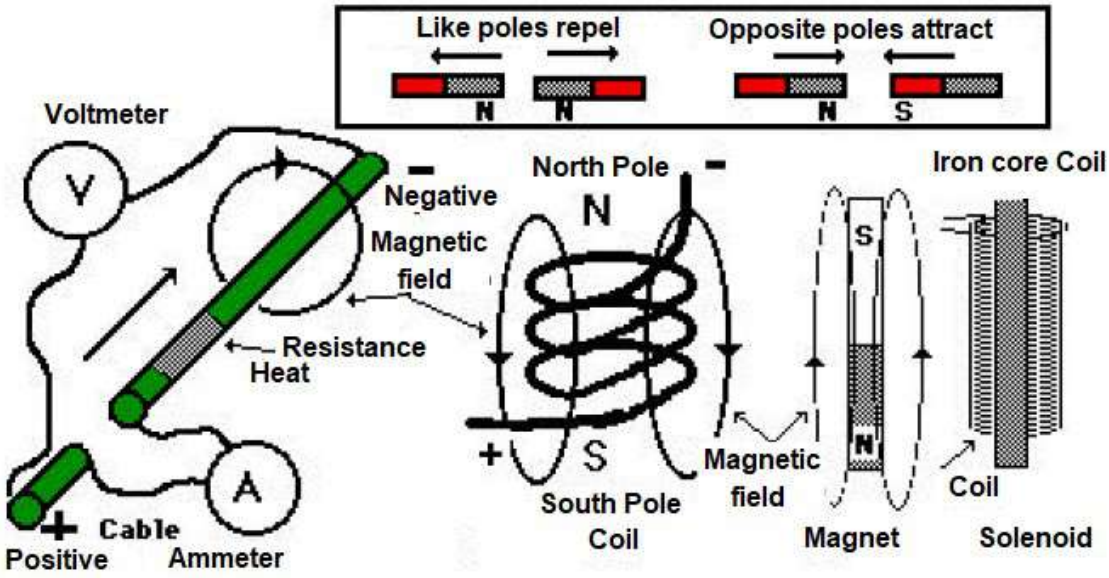
of the work capacity that a supply of a given voltage and amperage can perform.

The electric current that has a fixed direction of circulation: from positive to negative (+ to -, when in reality the electrons go from negative to positive), this current can be direct or alternating (in the first the electrons always go in the same direction: a car battery, cell, etc.).

In the second, the electrons go one way for one period of time and the other way around for another period: like the current supplied by an alternator or the current supplied by UTE, which is 50 cycles per second, that is, it changes direction 50 times per second to each side).

When we talk about a power supply, to define it we must specify in each case: if it is direct current (DC), the voltage and the available or desired amperage.

But if we are talking about alternating current (AC), we must specify the voltage, the amperage, and also the frequency (cycles or periods per second, or Hertz).



Useful Properties of Electricity:

When an electric current passes through a conductive wire, two important things occur: heat and a magnetic field.

The heat is the result of electrons colliding with the atoms that make up the

wire. This heat is greater the more electrons pass through the wire and the greater the resistance the wire offers to the flow of electrons: this property is called the electrical resistance of conductive materials.

Electrical resistance is a property of each material, but it also depends on the wire's cross-section and length.

A good conductor has low resistance. Listing materials from lowest to highest specific resistance, we have: gold, silver, copper, aluminum, iron, etc.

A thick wire has lower resistance than a thin wire, and a long wire has higher resistance than a short one of the same cross-section.

This electrical resistance is detrimental to the transmission of electricity or its use in magnetic applications (solenoids, motors, etc.), but it is useful for transforming electrical energy into heat (water heaters, oil heaters, electric boilers, incandescent lights, etc.).

Electrical cables are generally made of copper (or aluminum in some cases). They must be thick enough (with a cross-sectional area) to avoid losing power or voltage when carrying current from one place to another, and the further apart the cable is, the thicker it needs to be.

This is governed by Ohm's Law, which states that the amperage (A) flowing through a conductor is greater with higher voltage (V) and less with higher resistance (R): A = V/R.

Electricity (the flow of electrons) also causes a magnetic field to form (a magnet is a metal: iron, which forms a magnetic field with a stationary north and south pole. We know that opposite poles attract each other in magnets and that they also attract magnetic materials like iron, which, when magnetized, behave like magnets).

This magnetic field becomes stronger as the current increases, and we can increase it by winding the wire to concentrate the fields. We can further increase it by placing a material that is easily magnetized, such as iron, at the center of the wire.

When we have a wire wound around a coil to increase its magnetic field, it's called a coil, and when this coil has a core or central iron element, it's called a solenoid.

There are magnetic materials, meaning materials that are easily magnetized,

like iron; there are materials that are not magnetic or only slightly or not at all magnetizable, such as stainless steel, copper, etc.

The magnetic field formed can be continuous or alternating, depending on the current that creates it. These fields have many useful applications; they operate solenoid valves, contactor solenoids, electric motors, and so on.

Electric motors operate by the rotation (or attraction and repulsion) of magnetic fields generated by the current in their windings. Conversely, when a conductor is cut by a moving magnetic field or subjected to a changing magnetic field, an electric current is induced. This applies to generators, alternators, transformers, and so on.

Safety in the use of electrical current:

Electric current must be handled with great care and respect, as at a certain voltage it can kill a person (sometimes with voltages below 100 volts, alternating or direct current, a small electrical current passing through the human heart (a few milliamps) can stop it by causing a muscle contraction).

The voltage required for this to be sufficient depends on the conditions of the "electric shock"; a person who is wet or wearing shoes with hard soles is more vulnerable, etc.

Electrical Safety: At high voltages, when current flows through the human body, it not only causes contraction but also burns.

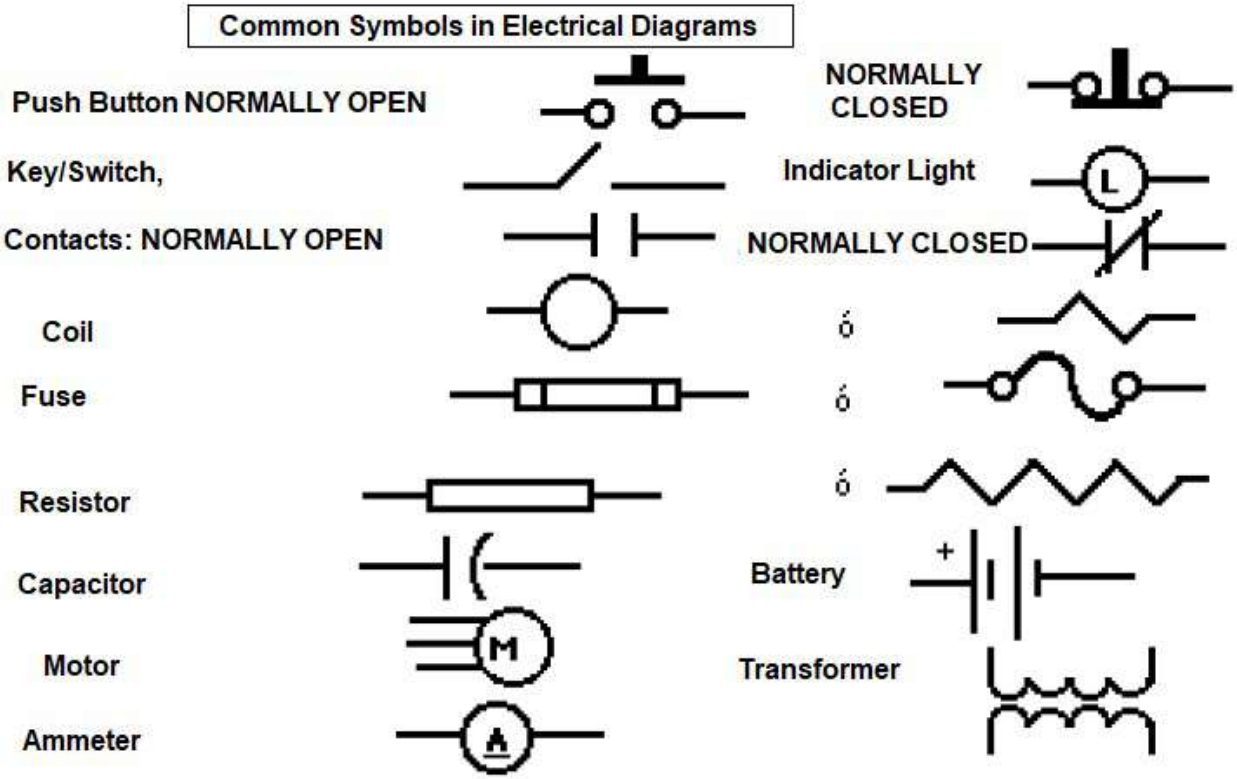
Even at low voltages, a short circuit can be dangerous. This occurs when two current poles are connected, and because the resistance is so low, it causes a "heat explosion" (due to the high current) that can burn us. (For example, connecting two battery poles with a thick wire or a metal tool produces such a high current that it creates a spark that burns and can cause the battery to explode due to the release of gases and heat.)

Electricity must be handled with knowledge and not as a "touch-and-feel" to see what happens, since mistakes can not only be fatal, but can also cause failures that can be very costly.

To work with electricity, you must also be in good physical condition; that is, wear shoes with insulating rubber soles and be dry.

Completely cut off the power (turn off switches or remove fuses) if you are working on a circuit (put up a sign to prevent anyone from reconnecting it

while you are working), avoid short-circuiting (connecting two wires or elements of different polarity with a jumper that easily conducts current), and use the appropriate tools (pliers and screwdrivers with the correct insulation).



Electrical Circuit Components of Boilers:
Electrical circuits are drawn in two ways:

a) Schematic drawing: This is the simplest way to understand how the circuit works. Terminals are omitted, and connections are made directly between components.

b) Diagrammatic drawing or the circuit "wiring": This shows the position of each component on the panel, the terminals, and the position of each interconnecting wire.

(This diagram allows us to "wire" the components to assemble the panel or trace the wires to find faults.)

Both diagrams should always be readily available on the boiler's control panel. To do this, we need to know the symbols used in the drawings (there are several ways to represent a component depending on the country of origin; we have included some examples).

The fuse:

This component serves to limit or prevent excessive electrical current from passing through a wire, causing it to burn out. It also protects the circuit or equipment supplying the current. (It is the first component we encounter when connecting any electrical load).

It is made of a thin conductor that "heats up" when current passes through it. If the current exceeds a certain value, the heat "melts" the conductor, cutting it. (The conductor is normally immersed in insulating powder so that the heat does not dissipate too quickly). It acts in cases of both overload (I > In, for example, double) and overcurrent (I >> In, for example, 10 times).

There are fast-acting and slow-acting fuses (or fuses in between).

Nowadays, modern thermomagnetic circuit breakers are used; where "I >" is the thermal element that acts in case of overload, and where "I >>" is the magnetic element that acts in case of overcurrent.

Fast-trip circuit breakers are those that barely exceed the current limit: they "trip" and are used to protect control and lighting circuits.

Slow-trip circuit breakers allow the current to momentarily exceed the set value: they are used to protect circuits connected to electric motors, since these draw a lot of current when starting. They are identified by class or type: gG, gL, or aM with different curves.

gG for general distribution,
gL for pure cable protection,
aM for motor feeders

Whenever a fuse blows, the cause of the short circuit or overload must be investigated, and the correct type and rating of fuse must be replaced. Do not use fuses or wires of a higher rating (this risks damaging the entire circuit).

Fuses come in various physical forms: cartridges, plugs, etc. They must make good contact; otherwise, they will heat up and melt even without an overload (this is the first component to inspect when a fault occurs, but before replacing it, investigate why it blew).

Thermal circuit breaker (I > In):

This device connects or disconnects an electrical circuit like a light switch. It has a thermal element for each wire it connects. When current flows through it, this element heats a bimetallic strip that acts as a trip mechanism, opening the contacts if the amperage exceeds a certain value (overload).

When an overload (high amperage) occurs, this circuit breaker trips. To reset it, you must wait a while for it to cool down before pressing a button or pushing the reset lever in reverse to reset the circuit breaker so the switch can close its contacts again.

In some cases, it does not replace a fuse, as it does not protect against short circuits because it takes a relatively long time to trip.

Thermal-magnetic circuit breaker (I >> In):

This circuit breaker is similar to the previous one, but in addition to tripping on overload, it also trips on short circuit (quickly). Each connecting wire has a magnetic trip (solenoid trip) that, upon detecting a rapid overload, triggers a mechanical trip.

Once it has "tripped due to overload," it must be reset, waiting, if necessary, for its bimetallic elements to cool down if they have heated up.

It is more complete than the previous circuit breaker and serves as the main switch for a panel that powers controls and electric motors. On its own, without a thermal element, it does not completely replace fuses; a fuse is always a simple and reliable protection.

The thermal-magnetic circuit breaker (I > and I >> protection elements) does replace a fuse.

Contactor or "starter":

this term can be used to describe the "switch" or switch that supplies power to an electric motor. It typically consists of a set of fixed contacts connected by moving contacts, which are actuated by a coil or solenoid acting on a mechanism.

This coil is powered by the current between "phases" (between conductors) through contacts (command buttons, auxiliary contacts that maintain the coil after we have released the "start button" (memory) and contacts that are handled by the thermal-magnetic overload and differential elements: current difference between phases (protects the three-phase motor from running without one phase, while running or at the moment of starting, since for this reason the motor can "burn out" due to overheating).

The starter may consist of one or more contactors connected in a way that allows for a direct start, a resistor start, a transformer start, or a star-delta start.

These different contactor configurations are necessary depending on the motor's power and load during startup. Motors draw a high current, which may be so high that the electrical installation cannot handle direct starting. Or like when the engine cannot start because of the type of equipment it is pulling: a pump is not the same as an air compressor, etc.

Motors over 5 HP should not have direct start. The contactors have thermal overload relays (and magnetic relays in some cases to protect against short circuits) that must be calibrated according to the maximum amperage the motor can handle.

Once calibrated, this rating should not be increased (otherwise the motor will burn out in an overload), and each time the relay trips, there is a reset button to reset the mechanism (after the thermal overload relays have cooled down).

Whenever a thermal overload relay trips, the problem must be investigated (motor braking due to mechanical overload, loss of a phase, worn bearings, friction in the bearings or motor rotor, etc.), since excessive resetting of the mechanism while the motor is overheated will cause it to burn out.

The starter contacts should be inspected and cleaned periodically (don't forget to replace the spark arrestors or spark eliminators), and all connections to the wires should be tightened (loose connections cause overheating).

Contactors (starters) are classified by the current or power they can handle and the frequency or number of starts or loads per hour they will be subjected to.

Currently, electromechanical starters are being replaced by fully electronic starters, which have no electric contacts. N**ot to be confused with frequency/speed inverters or drives.**

Instead, contact is made by a solid-state semiconductor (such as a transistor, called a thyristor in alternating current), which is controlled by an electrical signal to trigger or cut off the current.

This system also replaces star-delta starters, allowing electronic starters to control the starting current according to preset parameters in the control circuit.

Similarly, there are already electronic starters that control the current frequency, allowing alternating current motors, whose speed or RPM is constant if the frequency is constant, to be regulated to different revolutions by varying the frequency and the applied voltage (this is very convenient where it is necessary to regulate the motor speed, such as in a fan, pump or compressor, saving electrical energy, since with traditional flow regulation power is lost (because regulation slows, diverts or returns the flow, now it simply manages the desired flow by varying the speed of the system).

Programmers:

Programmers are electronic-electrical or electro-mechanical devices that control the sequence of operation of the various components involved in the boiler's functioning.

Once they begin their "program," they first turn on the fan to purge the gases, then ignite the pilot light (spark or gas and spark). They have a combustion-sensitive element (photocell) that allows them to "see" if the pilot or main flame has ignited. If this operation fails within the first few seconds, the programmer stops and can restart the process in smaller liquid-fueled boilers (if it repeats and still fails to ignite, it stops and sounds an alarm).

In liquid fuel boilers exceeding 700,000 kcal/hour (> 1 million BTU/lb) and all gas-fired boilers, there will be no automatic recycle or restart.

To restart, the boiler operator must press a "reset" button. If the main flame ignites within a certain number of seconds, combustion is established and monitored by the flame-sensitive element (a photosensitive element or photocell sensitive to infrared light, and ionizers or ultraviolet light sensors in the case of gas combustion; the response time—the time it takes to detect the absence of a flame—will depend on the size of the burner and the type of fuel).

Every programmer is the "brain" of the boiler control circuit, but it depends on the level controls and the pressure switches, thermostats, etc. that enable it.

Pressure switches:

We have seen in previous chapters how they are connected and what their function is. Their contacts allow the operation of programmers or flame controls (modulating, on/off, etc.).

Pressure switches control the operation of the programmer and should never be removed from the control circuit, as they are what shut down the boiler once it reaches maximum pressure.

Thermosets (temperature switches);

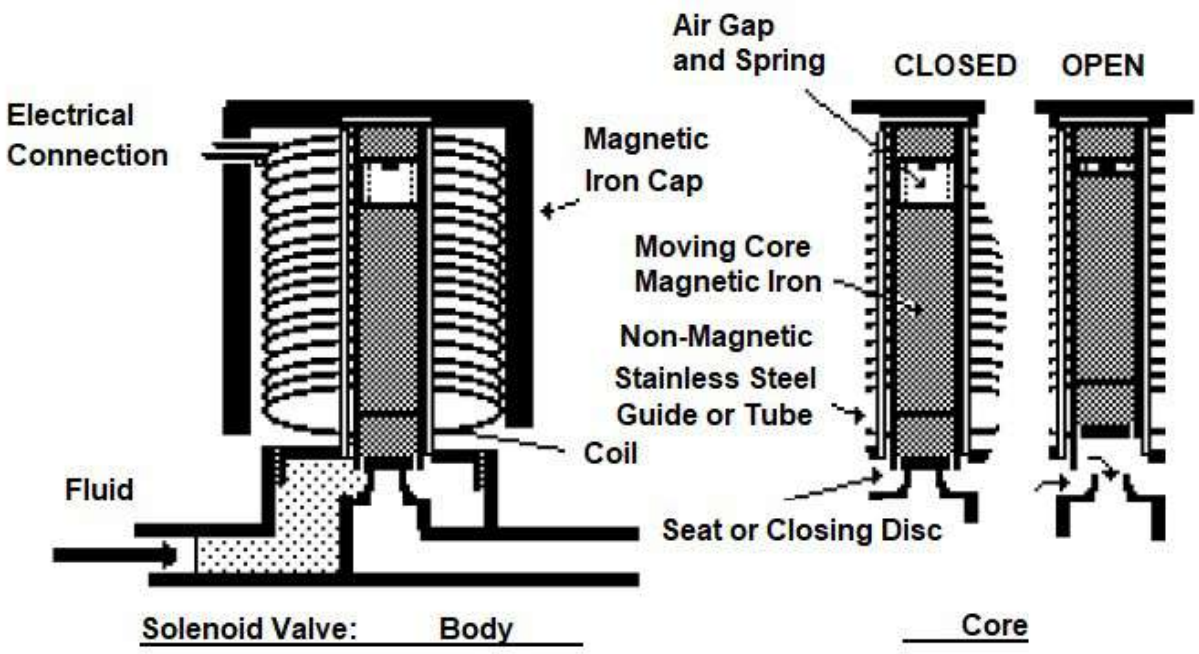
are generally used in hot water boilers or for temperature control of heavy liquid fuels (heavy fuel oil and heating oil).

Level controls:

We have also looked at level controls. These have contacts that enable the boiler's control circuits (programmers and manual control) so that they "cut off or turn them off" if the water level drops to the minimum permissible value. They also control the feed pump contactor.

It is advisable to have **two level controls** so that each phase of the control circuit is interrupted in case of a low level.

It can happen with only one level control that if one of the control wires is grounded, the level control contact will not activate because it is "bridged" to ground. This reduces the danger posed by ground faults or short circuits in the wires.



Solenoid Valves:

Electrically controlled remote valves are generally solenoid valves. A solenoid (a coil with an internal metal core that acts as a magnet when current passes through it, usually alternating current; the magnet's pole will change with the current's frequency, but the mechanical attraction will remain the same) acts as a magnet, "lifting" or "pulling" a magnetizable iron stem (which moves inside a non-magnetic metal tube, usually stainless steel) attached to a valve "disc" (made of metal or Teflon, which seals against a seat), allowing fluid to pass through.

These solenoid valves are used as pilot valves when the flow rate is very high, because the solenoid itself does not have enough force to lift a large valve "disc" (this also depends on the fluid pressure). This pilot valve acts as a control for another valve actuated by the same fluid.

The Electric Motor:

An electric motor can be direct current (DC) or alternating current (AC) (it is normally AC, and can be single-phase or three-phase). To define a motor, we must establish the voltage, the amperage (or power in kilowatts: kW or horsepower: HP), whether it is single-phase or three-phase (AC), the frequency in cycles per second (50 Hz or 60 Hz or Hertz), the revolutions per minute (RPM), the type of rotor and winding (induction: squirrel cage or wound rotor), the type of winding connection (star and/or delta), the type of construction (semi-open or closed), the type of insulation (which defines the maximum operating temperature), the type of bearings, etc.

The important thing is that once it's running, it must be kept free of moisture, prevented from overheating (due to excessive amperage or load), and prevented from operating with abnormal vibrations (ensure it's properly aligned with the pump or equipment it drives).

Preventive maintenance
should be performed according to usage: such as measuring the amperage per phase (on 3-phase motors), checking the winding insulation and cleaning it (keeping it dry and dust-free), replacing the bearings at both ends of the shaft as needed, etc.

To prevent the motor from burning out due to overload, it must be used with a good contactor that has differential thermal protection (this protects the balance between phases; if a three-phase motor is left on two phases, it will overheat and its windings may burn out even with thermal protection; this should not be confused with differential ground fault protection).

Its fuses should be (generally time-delay class aM) as close as possible to the minimum amperage rating required.

When a squirrel-cage induction motor vibrates, and after replacing the bearings, dynamically balancing the rotor, etc., it continues to vibrate, the fault may be caused by a break or cut in the rotor's squirrel-cage bars (in this case, a new rotor, i.e., a new motor, must be installed, since replacement rotors are generally unavailable, and it is not possible to repair the bar outside the rotor's electrical circuit).

The starting method for a three-phase motor is very important, since at startup, if the rotor is not specially designed, the starting current can be up to five times or more than the nominal value.

For this reason, at certain power levels (generally above 5 HP), special electric starters are used. (In the past, rotors were wound and started with resistors placed between the rotor windings via slip rings with carbon brushes, which were short-circuited once the motor started. More modern rotors have a special construction within the squirrel cage itself to reduce the starting short-circuit current.)

If the rotors were not special, starters with resistors or transformers were used to limit the current in the line. It was also possible that if the motor could be connected in a star-delta stator winding, this effect was used in the starter (star-delta starting).

Since this last possibility is not available, meaning the motor is necessarily started directly by its voltage, it can now be controlled using electronic starters that limit the current on the line itself. This modern system is now used instead of starting resistors or transformers.

Not just any system can be applied; the load and type of mechanical load connected to the motor must be studied, as starting a pump, a fan, or a compressor is not the same.

Today, variable speed (RPM) of electric motors
is achieved electronically (previously it was done mechanically or electrically, such as with wound rotors), but electronic frequency regulation, by varying the RPM of electric motors, has very important applications in fluid handling, since we can establish the electrical power necessary for the flow and pressure conditions of the fluid, saving a lot of electrical energy and many mechanical elements that are no longer needed.

With these regulation systems, induced draft and forced draft (primary and secondary) can be automatically controlled, seeking the best operating conditions for an appropriate response to changes in steam pressure and flow rate, maintaining optimal combustion conditions.

However, the converters do not regulate from 0% to 100%. In the first part of the regulation, modulating motor-driven "shutters" must be used to cover the area that the converter does not cover (approximately 0% to 30%).

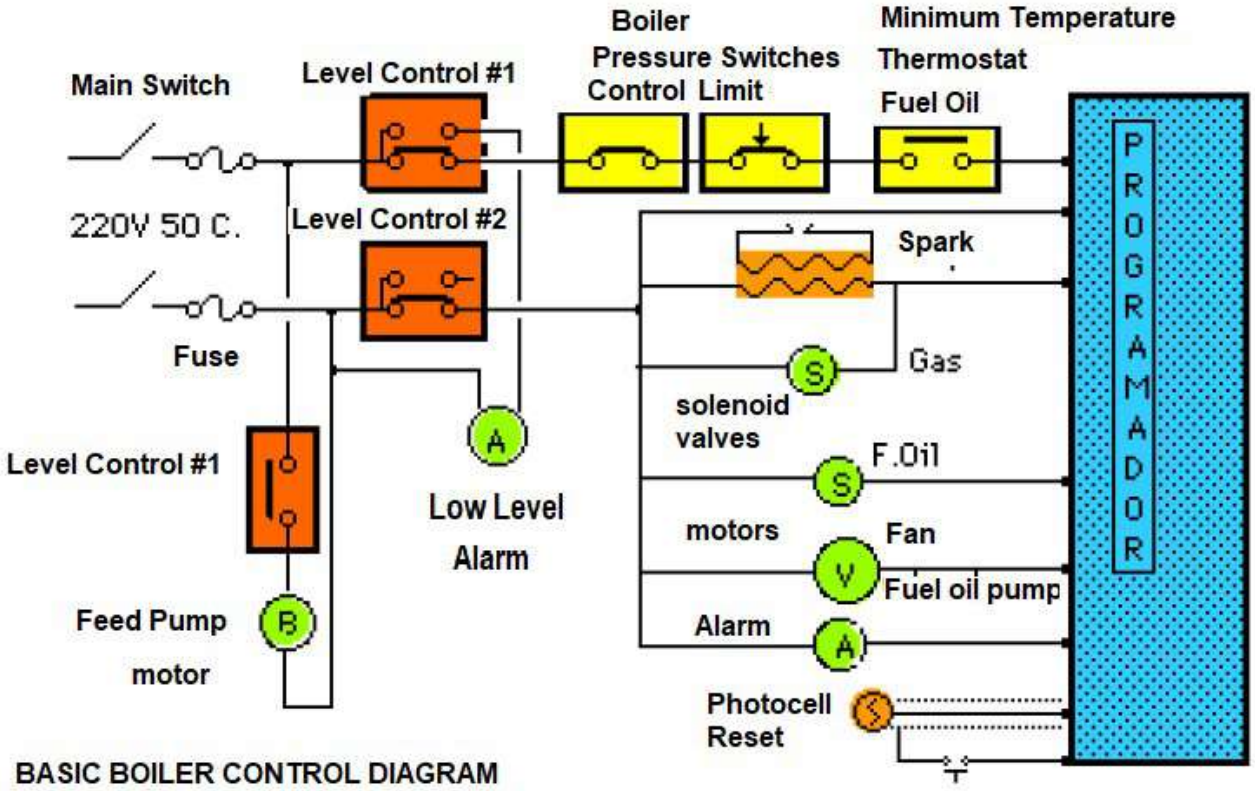
For example, a wood-fired boiler can maintain combustion negative pressure by controlling the induced draft RPM and maintain steam pressure by controlling the RPM of the fans below the grate (primary and secondary).

Or, in small boilers,
the motors can be controlled directly with the steam pressure and an electronic controller for each motor, controlled by a controller with independent outputs. **This controller allows for the adjustment of all PID parameters (proportional to the signal, integral to the deviation, and derivative to the rate of change of the signal) and/or manual control of all or each of the controllers** (something unthinkable until a few years ago, since it saves electrical energy and achieves very good control if the PID settings are properly adjusted).

This can be improved by controlling the secondary air intake using an oxygen meter in the chimney that regulates excess air, thus varying the RPM of the secondary fan.

Let's look at a basic boiler control system:

This system can be both AUTOMATIC and MANUAL. Both systems should have a maximum pressure limit set by a pressure switch (a standard control pressure switch and a maximum pressure limit switch with manual reset).



In this case, we draw a diagram of an automatic circuit without MANUAL control.

This basic diagram lacks the fuel oil heating system, the power circuit for the motors, the lights and audible alarms indicating faults and operation, and manual ignition, etc.

It shows the bare minimum for the operation of a boiler with a single-flame burner and two level controls (the second is a safety feature in case the first one fails).

The programmer:

generally has a function that repeats a second start attempt if the first one fails due to a lack of flame detection. If it fails a second time, it will shut down and an alarm will sound (gas burners, including those using higher-power liquid fuels, will not have a restart cycle if ignition fails; the burner will remain locked until the boiler operator resets it).

To restart the cycle, the "reset" button must be pressed, which resets the programmer for a new cycle. It has a thermostat to prevent operation with cold fuel oil: this avoids poor atomization (resulting in combustion that would foul the boiler and also make ignition difficult, causing "pops" or "pulsations" in the firebox).

Electrical Maintenance:

A good practice is to keep the control panels clean and free of dust and moisture. Test at least once per shift (6 or 8-hour shifts) that the level controls shut off the burner when fully purged (simulate a low level with the burner lit).

Test the photocell's operation with the burner lit: cover it from the light and see if it shuts off the burner (then press the "reset" button).

As a precaution for the electrical system, keep the following on hand: several sets of fuses, spare solenoids for gas and fuel oil, and a new or refurbished programmer (that has been tested and is working).

To test the programmer,

a good practice is to connect it in the workshop with lamps as if they were the coils or loads.

This way, you can observe the lamps' operation when power is applied

(remember to manipulate the photocell; that is, cover it initially until the gas and spark indicator lights up. If it "sees light," it does not enable the programmer).

This allows you to observe the ignition sequence and measure the timing of each stage (with the photocell covered, the fan first turns on: "sweep," then the gas and spark, uncover the photocell, and finally the fuel solenoid turns on.

Cover the photocell and observe the cycle repeating.
Leaving the photocell covered should trigger the alarm. Press the "reset" button, and the cycle should restart).

In some cases, it is advisable to have two pressure switches:
one for start-up and shutdown, and another for maximum pressure cutoff in case the first one fails.

It is recommended that this pressure switch be manually resettable, meaning that if it activates, the boiler will not restart until the operator resets it by pressing a "reset" button.
NEVER FIT AUTORESET PRESSURE SWITCHES

If the high-pressure cutoff switch fails, only the safety valves will act, releasing the pressure to the atmosphere.

For this reason, the safety valves must be of adequate quality and size so that each one is capable of releasing all the generated steam, with a minimum of two per boiler.

Solenoid valves must be kept clean and dry externally. Remember to replace their metal cap or cover, as it is essential for proper operation (it forms part of the magnetic circuit that acts on the stem; not only will the valve lose actuation force if it is not covered, but in alternating current applications, the coil will overheat due to excessive current flow, as the self-inductance necessary to limit the current decreases).

Safety valves (not to be confused with relief valves, which are not the same), as well as other control and command elements, must be protected both inside and out, and should not be painted on days when the boiler room is being painted. Painting a control element or safety valve can cause it to malfunction or become "locked" by the paint when it gets into its internal mechanisms.

Cables passing through high-temperature areas must be mechanically protected (in conduit) and made of heat-resistant material. These cables should be replaced every few years (maximum of 5 years).

Never leave the control panel, level control valve covers, and pressure switch covers uncovered; they will accumulate dust and attract cockroaches. This dust and cockroaches can cause short circuits, jammed mechanisms, dirty contacts, etc.

The control panel should be kept clean and its terminals numbered, with schematic and diagrammatic drawings readily available so that malfunctions can be quickly diagnosed and repaired.

Every boiler should have a main electrical shut-off switch at the boiler room outlet so that in the event of a steam pipe rupture that could flood the room, or in the event of a fire, the power can be cut off.

All electrical components of the boiler must be properly grounded: motors, control panels, etc., to prevent live parts from being touched by someone (which could be fatal).

COMMENT:
The safety of a boiler is closely linked to its electrical and electronic controls (the entire operation of an automatic boiler depends on sensors: pressure switches, level controls, etc.) which, to function, must be connected by insulated conductors (wires insulated from each other and from ground, and capable of withstanding the high temperatures found in some locations).

Any fault that could connect two wires together or a wire to ground (there is usually already a ground wire in the installation due to insulation failure in the electrical distribution system) can cause a false reading of the control status and thus lead to a very serious malfunction.

If a pressure switch malfunctions and indicates a false reading, the burner may not shut off (in this case, only the safety valves can save us, as they open and maintain the pressure below the design limit).

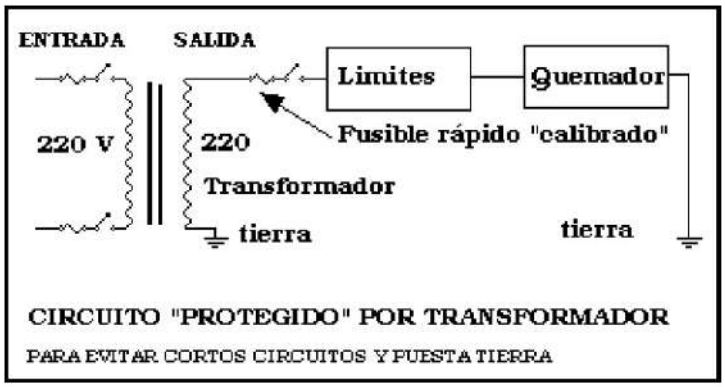
However, if a level control indicates a false water level and there is no backup control, the low-level cutoff can be overridden.

But even with two level controls, if the wiring fails at a point where both low-level cutoffs are overridden, the burner will remain lit without water, causing

the boiler to burn out and creating a risk of explosion, especially if water suddenly enters when it is red-hot. Even so, the boiler can still be lost due to overheating and deformation.

Crack in the top plate of a fire-tube boiler

Part of the solution to these cable problems (both short-circuiting and grounding) is achieved by installing a power transformer at the control current input (a transformer with separate primary and secondary windings, not an autotransformer, to isolate the distribution system from the boiler control). One of the transformer's outputs is grounded, and a fast-acting fuse (set to the current rating) is placed on the live line. This way, if the cables short-circuit or ground, the fuse blows, and the burner is deprived of control current (shutting down).

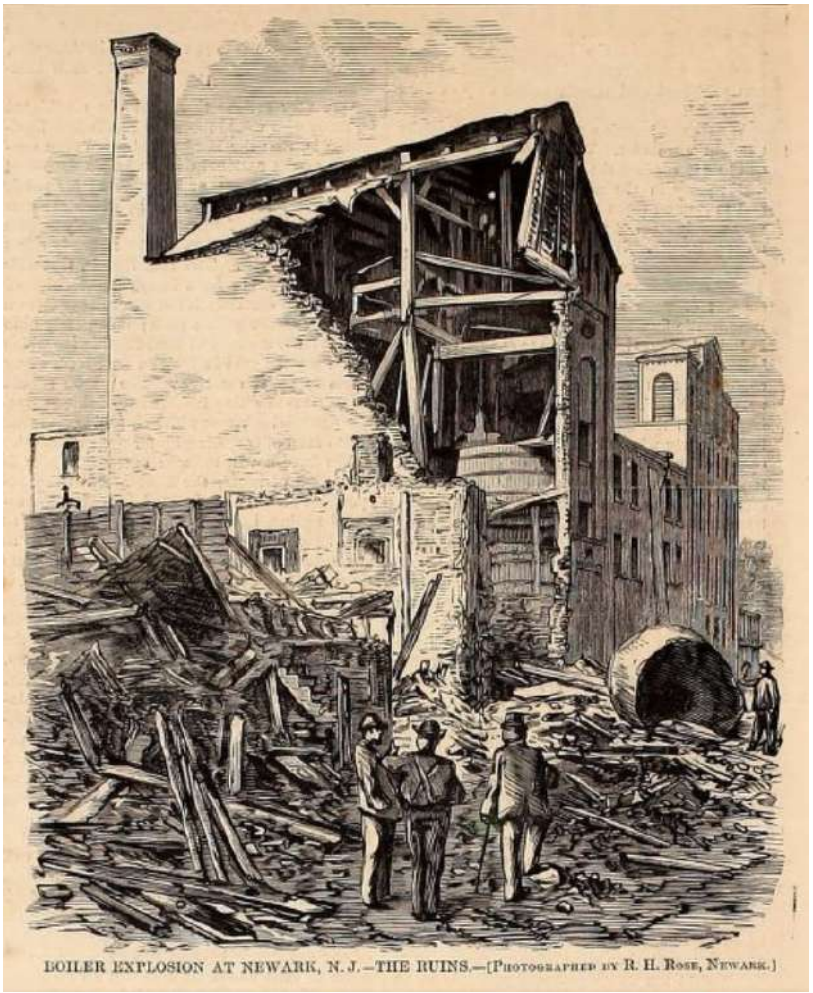


With our father CWT (Carlos Walter Thomasset) and sister.
CIRCA 1972

CHAPTER 11: Boiler structure failure

MOST COMMON FAILURES IN BOILER STRUCTURES

The most common causes of boiler failures do not occur due to faults in the pressure vessel (metal shell, plates, domes, headers, and tubes), since these are built under strict construction standards (both in terms of design, which must respect the internal circulation of water or steam, the mechanical effect of pressure, the thermal and chemical conditions to which the material is subjected, as well as its composition, shaping, welding, stress relief, hydraulic testing, non-destructive and destructive testing (in case of doubt), etc.).



BOILER EXPLOSION AT NEWARK, N. J.—THE RUINS.—[PHOTOGRAPHED BY R. H. ROSE, NEWARK.]

Most boiler failures are caused by various auxiliary elements related to boiler operation and safety (electrical, electronic, mechanical, pneumatic, and chemical) and human error (when the boiler operator's training is inadequate).

Therefore, we can say that technicians working with boilers must not only have machines or engineering background but also "aptitude," which comes from experience and a genuine interest in boilers.

Since the "boiler operator" is the person who is constantly involved in the operation of the boilers, special attention must be paid to their professional and personal development, considering all aspects of their responsibility, in which human life and the factory's finances are at stake (the boiler is a place where fuel can be burned improperly, causing significant losses).

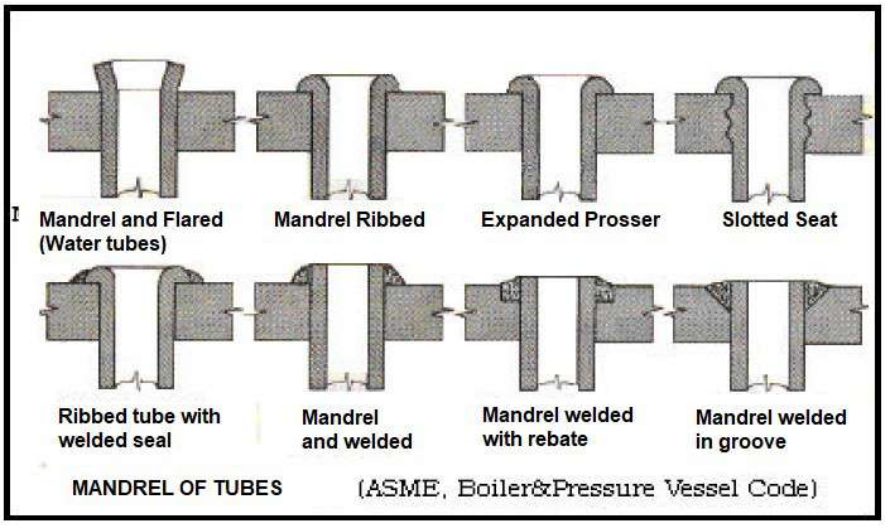
But in addition to efficiency, there is the need for most processes to continue uninterrupted (when a factory runs out of steam, many things are lost, not only lost profits, but also wages and salaries, and other inputs such as raw and semi-finished materials. In many cases, I believe there is no greater loss than forced shutdowns).

PROBABLE CAUSES OF BOILER TUBE LOOSEN IN FIRE-TUBE BOILERS:

The primary function of the tubes in fire-tube boilers is to generate steam from hot water (T > 100°C 212°F) and to provide structural support by holding the plates in position.

Therefore, the tube-to-plate connections must not only be leak-proof but also mechanically strong (maintaining the distance between the plates and preventing pressure from deforming them).

For these reasons, the tubes must be mandrel-grooved, welded, or flanged according to established standards.

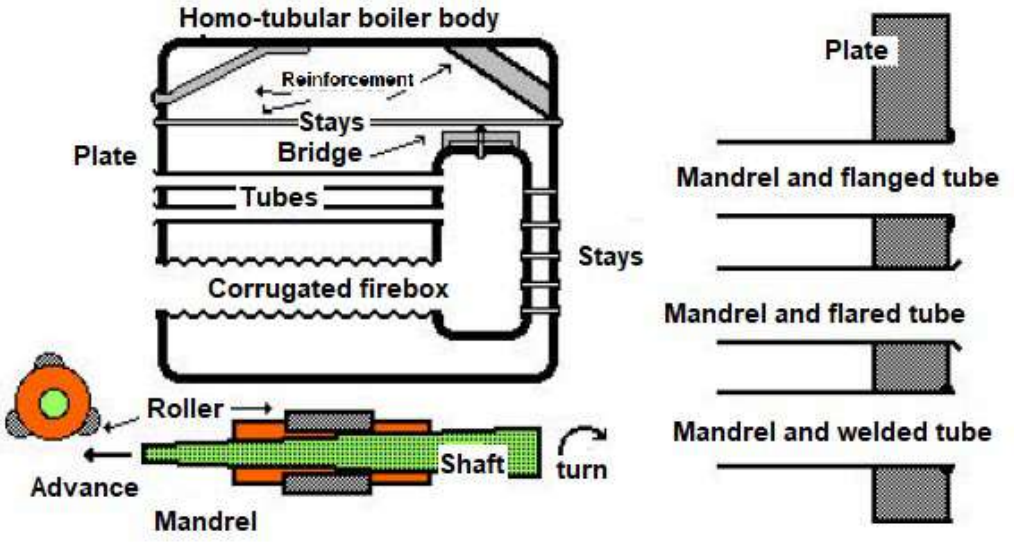


Meeting the above requirements, loosening of the tubes at their connection to the plates should not occur, but in reality, it does.

We can identify several causes for this loosening, which are usually attributed to **improper boiler assembly or inadequate material quality.**

The common element in all the failures we will mention is the expansion of the tubes and plates, which, due to temperature changes or differentials, causes abnormal stress between them.

For every 100°C (212°F) temperature variation and for every meter of iron material, there is an expansion of approximately 1.2 mm.

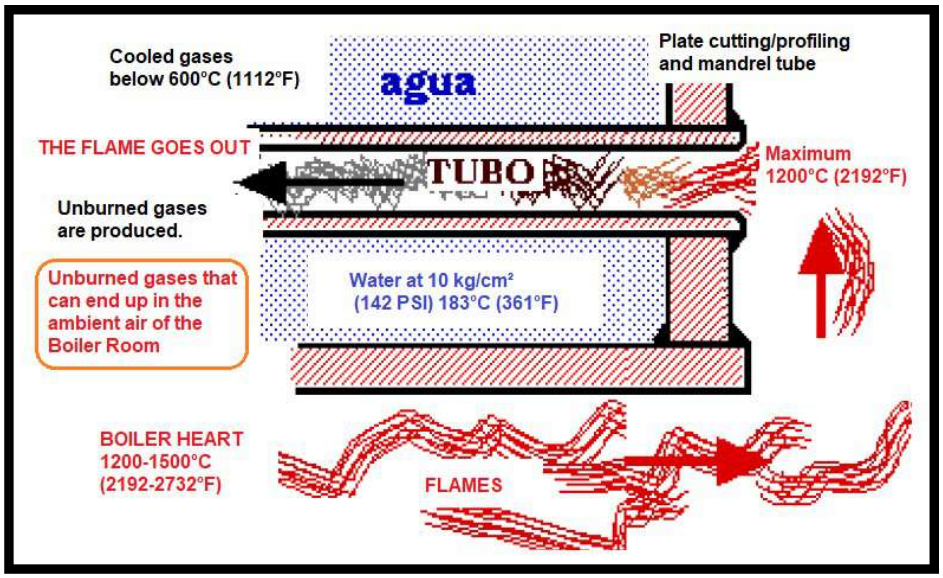


Let's look at the most common failure causes:

1-ENCLOSED BOILER:

If the tubes are embedded (the plate will usually be as well), the metal temperature increases, causing the tubes to expand more than normal (the tubes lengthen more than the boiler).

This greater-than-normal expansion puts stress on the joint between the tubes and the plates, which not only causes the joint to break but can also fatigue the plate (repeatedly deforming it beyond the material's limits), causing it to crack.



The plate itself will be overheated, which will raise the temperature in the mandrel area, facilitating loosening of the mandrel, weld breakage, and probable plate cracking (thermal fatigue: repeated exposure to high temperatures).

This, combined with the excessive stress on the tubes and plates, accelerates the aforementioned process.

The increased rate of vaporization accelerates this process (due to the increased temperatures from forced combustion), as do the chemical conditions of the water (high pH, high content of dissolved and insoluble solids, excess free alkalinity, etc., all of which increase the number of steam bubbles inside the water).

A boiler in these conditions (scaled or full of sludge) should be cleaned chemically and mechanically.

2-BOILER WITH POOR WATER CIRCULATION:

If the boiler is full of sludge or scale buildup that impedes proper water circulation, the tubes and plates are subjected to abnormal temperatures (heat transfer surfaces), causing differences in expansion, greater than normal expansion, thermal fatigue, plastic deformation (due to loss of strength from high temperatures), etc.

3-BOILER WITH CIRCULATION CUT OFF DUE TO LOW PRESSURE AND HIGH FIRE RATE:

This category includes boilers where pressures are allowed to drop excessively with a high fire rate or high flame (attempting to recover pressure).

This causes poor cooling of the tubes and plates, especially at the junction of the tubes with the hottest plate (causing insulation of the hottest plate due to larger steam bubbles as the pressure decreases, preventing proper contact between the water and the metal for adequate cooling).

Operation should be based on the design differential pressure (for example: design pressure shuts off the high flame - 10% below this pressure ignites the high flame or the burner), or by shutting off less important fuel consumption if normal pressure recovery is not possible.

If for some reason it is necessary to work with low pressures (for example 50% below the design pressure) it is advisable to reduce the maximum fire rate to an appropriate value.

These concepts will depend on the type of boiler and its use.

Some boilers already come with double protection for these situations: they have a pressure switch that only allows the high flame to activate when the pressure is above a certain value, meaning that at low pressure it is impossible to activate the high flame.

Another protection measure can be a restriction in the steam outlet valve (diaphragm or orifice plate), so that when the pressure drops and the volume of steam per kilogram increases (specific volume), the pressure inside the boiler tends not to decrease because the steam cannot escape easily (increased pressure drop in the outlet valve).

This also applies when starting the boiler; that is, it must be lit and heated slowly with a low flame until the working pressure is reached (by venting air through the atmospheric valve until sufficient steam is released; otherwise, the heating will be incomplete, as the pressure will be reached at a lower boiler temperature and there will be insufficient internal circulation for heat distribution, resulting in cold spots in the boiler water).

When supplying steam for use in the plant, do not allow the pressure to drop too low. If necessary, shut off some steam outlets and do not force

combustion when the pressure has already fallen below 50% of the working pressure.

4-FEEDING WITH COLD WATER AND RAPID HEATING:

In these cases, effects such as those already described occur, exacerbated by sudden contractions and expansions.

Boilers should be fed with the hottest water the feed pump allows, without cavitating (this improves boiler response, reduces dissolved oxygen, increases momentary nominal capacity, etc.).

Start-up should be slow until the operating pressure is reached, heating the feedwater as quickly as possible. Then, steam should be applied gently to avoid a sudden drop in pressure, as well as carryover and line heating with sudden surges.

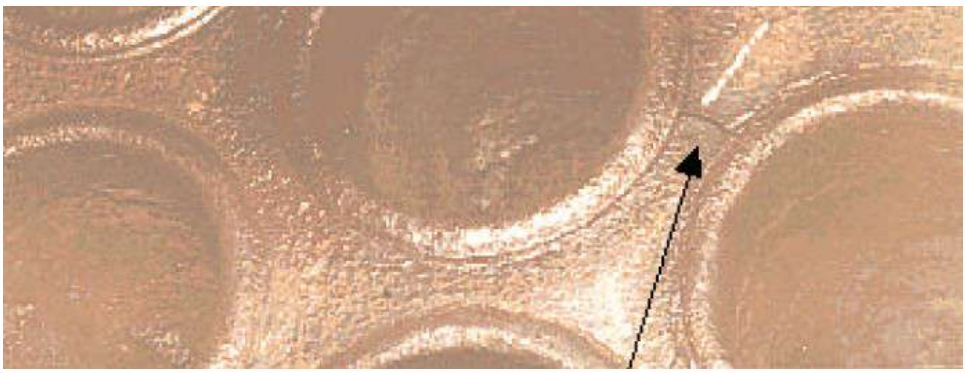
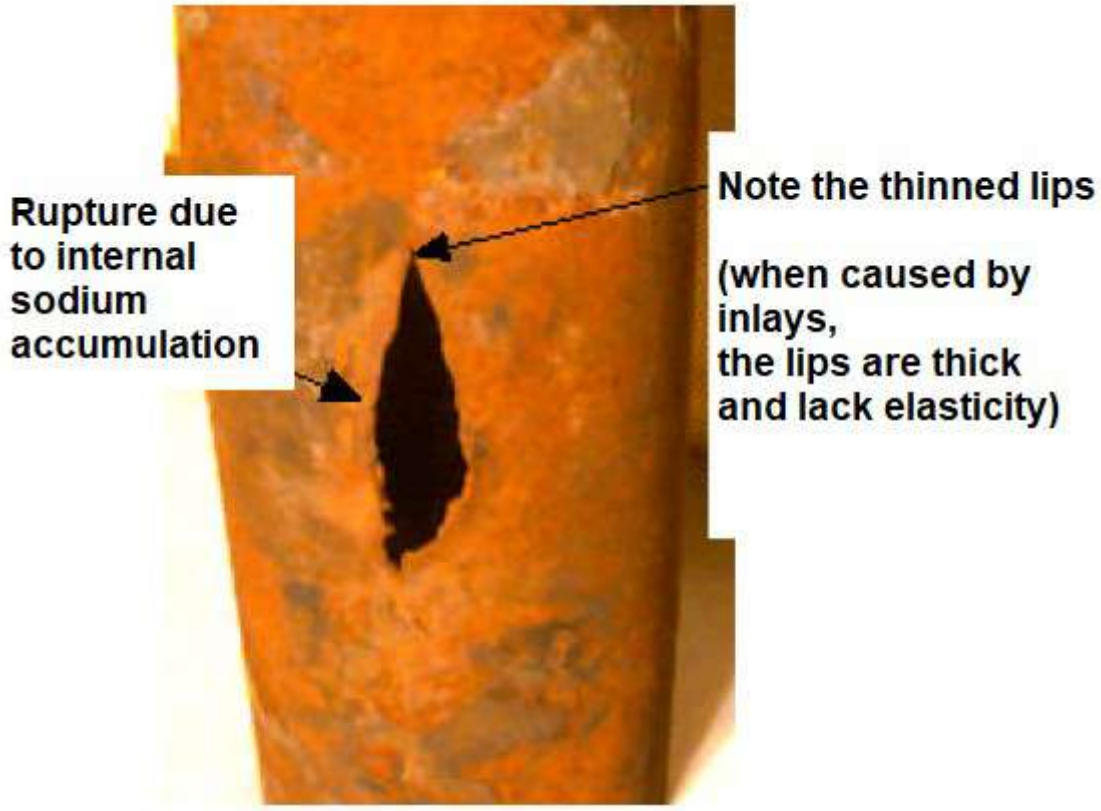


PLATE CRACKED BY THERMAL FATIGUE
caused by low steam pressure with maximum combustion.

The lower plate has developed a crack between the tube holes (which are subjected to the stress of the mandrel), due to insufficient cooling caused by the boiler operating at very low pressure and maximum combustion.

The vapor bubbles that form against the plate and tubes increase in size as the pressure drops, pushing away the cooling water, which causes thermal fatigue.

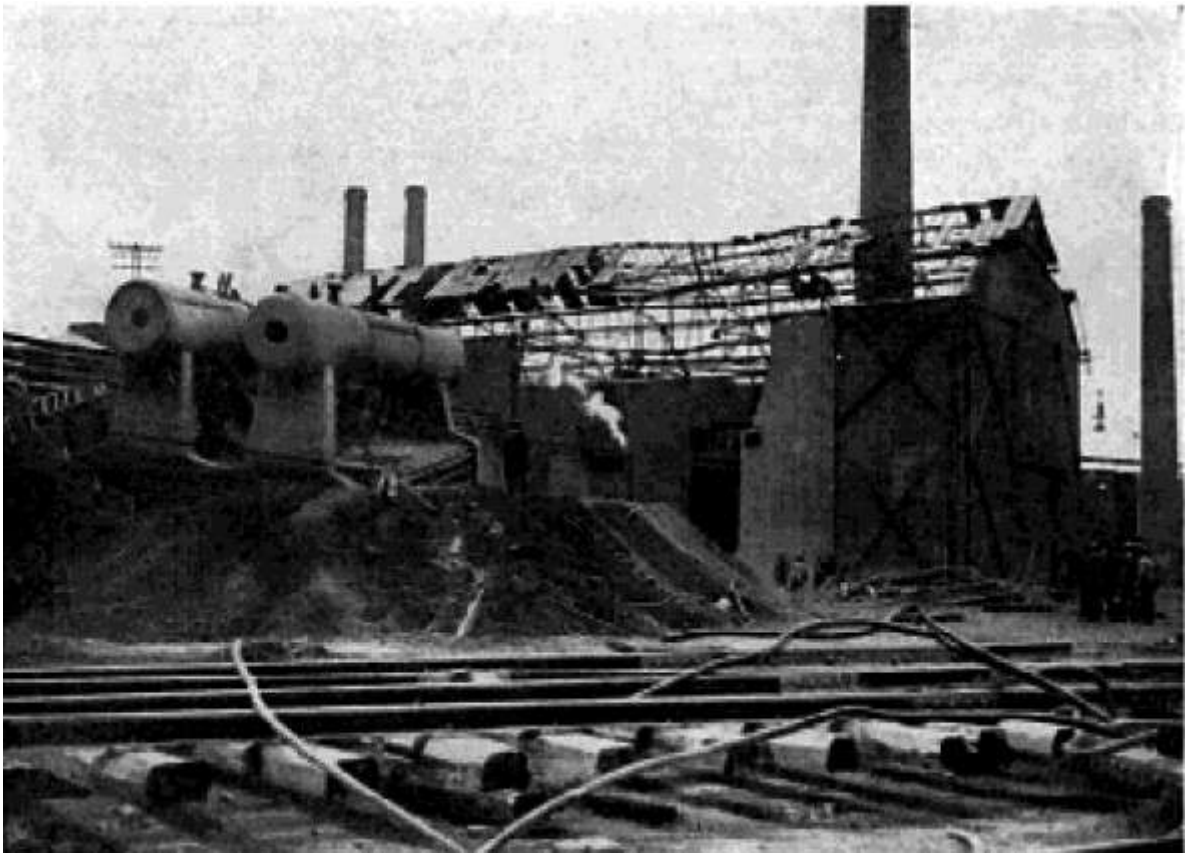
This lack of cooling not only increases when the pressure drops or combustion increases, but also under certain physicochemical conditions of the water, the bubbles increase in size (high pH, high dissolved or suspended solids, organic contamination, scaling, etc.).


Rupture due to internal sodium accumulation
Note the thinned lips
(when caused by inlays, the lips are thick and lack elasticity)

5- CHEMICAL CONDITIONS OF WATER:

The chemical conditions of water are linked to all the phenomena mentioned above. Essentially, the order of alteration is determined by: high alkalinity (primarily hydroxides), contamination with organic materials (fats, oils, milk, sugars, etc.), and total dissolved solids (plus suspended solids). These limits must be carefully managed.

These conditions affect the boiler's operation, since exceeding the permissible limits for each boiler—entrainment, level variations, and even the effect of spontaneous boiling (where the heat transfer surfaces are enveloped in steam rather than water)—can not only loosen the tubes but also allow overheating of the hottest plate and even collapse the furnace in high-speed boilers (those with high heat transfer rates).



Boiler room explosión
Phoenix pipe manufacturing plant after a boiler explosion in Düsseldorf-Derendorf, Germany.
The incident occurred on November 12, 1893.

6-OPERATING PROCEDURE:

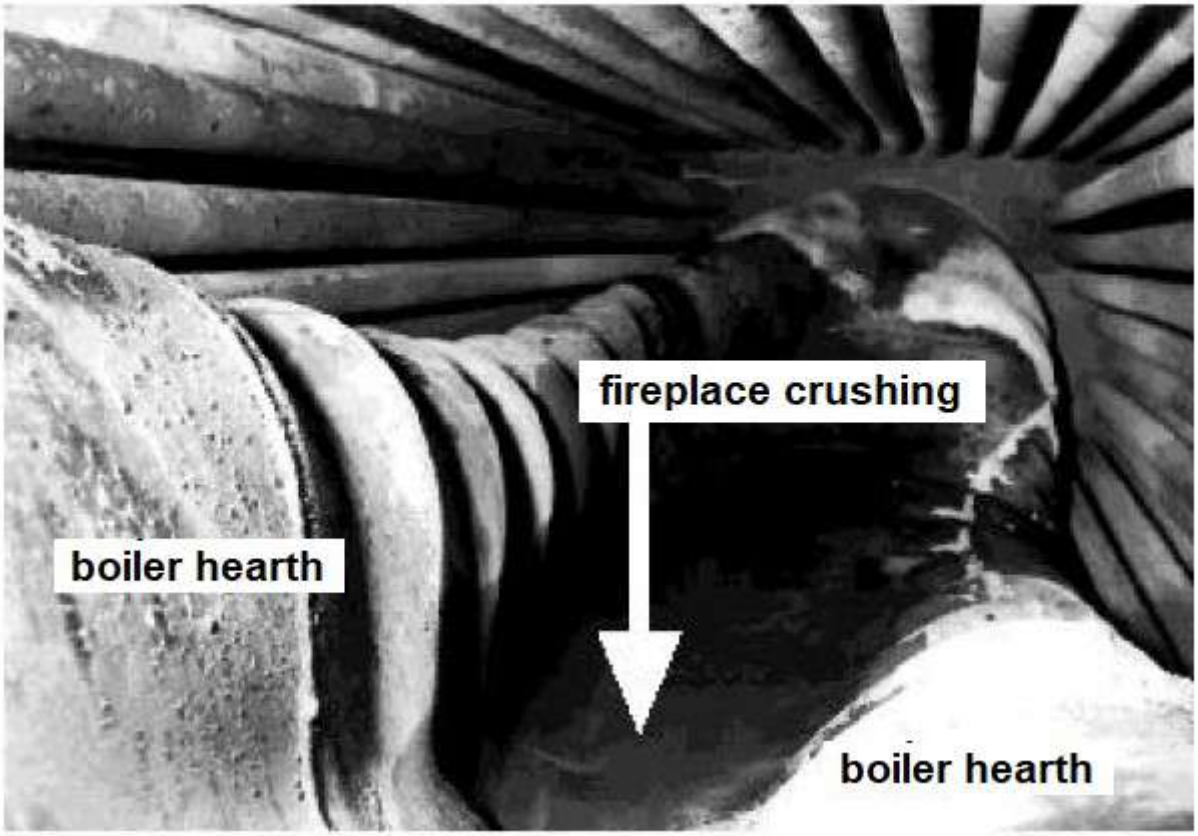
Never allow the water level to fall below the minimum level:
Turn off the heat and close the steam outlet if the boiler cannot be supplied with water (power outage, lack of water, pump failure, end of the workday, etc.).

Operations involving large steam valves must be carried out smoothly, never hastily or abruptly.

First, open a bypass valve (a small valve connected in parallel) to achieve initial heating of the lines, the steam distribution pipes, and the equipment to be supplied, including the steam consumption installations. This allows for the balancing of the boiler's vaporization process (water level inside, water circulation, pressure recovery, etc.).

A violent opening of a valve of a certain size can cause a large amount of water to be drawn in with the steam, a decompression inside the boiler that artificially raises the water level (you can see the levels rise, but in reality it is the same amount of water inside the boiler that rises due to the bubbles as the boiler decompresses), leaving the heat transfer surfaces without enough cooling water: steam is produced that insulates them, causing loosening of tubes, cracks in plates, and even overheating of the furnace.

FIREPLACE CRUSHED DUE TO APPARENT WATER LEVEL FAILURE



Poorly designed or operated purge (blowdown) valves—that is, blowdown valves located in areas where their activation disrupts water circulation within the boiler during high steam generation—cause localized overheating.

Bottom purges (blowdown) valves should not be operated at high steam generation rates: they are ineffective at removing sludge and also risk interrupting circulation within the boiler (continuous blowdown should be used to maintain acceptable levels of dissolved solids, pH, alkalinity, etc.).

The mud collectors on the walls of a cooled furnace (such as boilers with chapels, gas generators, water-tube furnaces, etc.) should not be purged with medium and high vaporization rates, and should be purged at times of very low or zero vaporization (fires extinguished with pressure in the boiler).

Always check that the bottom and level drains are working correctly, listening for the "noise" produced by the water flow and the flash steam that occurs when draining.

If the drain opens and does not perform its function of removing water with sludge, this sludge will accumulate and cause an internal circulation problem or blockage of the level controls, resulting in an accident.

COMMON CORROSION IN BOILERS

Localized Corrosion:

Fire-tube boilers are susceptible to pitting (localized corrosion) of the upper tubes when they are improperly shut down. The same occurs in water-tube boilers in the upper drums and superheaters.

The upper tubes, being closer to the water level, are exposed to the action of oxygen that enters when the boiler is shut down.

When the boiler water temperature drops below 100°C (212°F), a vacuum is created, allowing oxygen-containing air from the atmosphere to enter. This oxygen causes localized corrosion in specific areas, which, once it begins, is facilitated by the pitting structure itself.

If the boiler reaches a certain internal temperature, corrosion increases because the temperature accelerates chemical reactions (this occurs when the boiler receives steam leaks through the steam outlet valve from other boilers in operation).

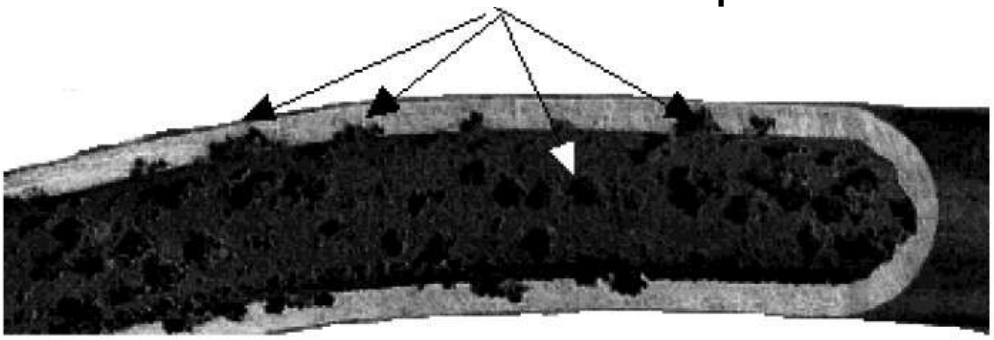
If the boiler is not chemically treated or is not even slightly scaled, this corrosion also accelerates (the use of softened or demineralized water without subsequent chemical treatment also facilitates this corrosion).

To prevent this corrosion, the boiler must be chemically treated with an oxygen scavenger (and have a suitable pH, above 10.5), and the water level must be maintained to prevent air from entering the boiler (keep it flooded with a water seal).

See the boiler maintenance chapter 7.

This type of corrosion also occurs in water-tube boilers, primarily affecting the steam drums and their steam separator accessories, as well as steam superheaters that are not properly flooded during shutdowns.

OXYGEN CORROSION ("pitting") WATER-TUBE BOILER
corrosion is localized in several points



<u>Localized corrosion due to metal differentials:</u>

Galvanic currents (actual electrical cells) are caused by the voltage that develops between different types of metals when they are submerged in boiler water. This water conducts electricity because it contains salts that dissociate into ions. For example, copper-containing materials tend to corrode tubes, casings, and plates made of special mild steels used in boilers.

Stainless steel and cast iron also behave like copper, but less strongly. These galvanic corrosion conditions are avoided by avoiding the use of metals that can attack iron, and also by the chemical composition of the water, which plays a fundamental role, conditioning the iron surfaces to resist electrical corrosion and preventing the iron from dissolving in the water.

In the past, zinc "sacrificial" elements—anodes—were placed in boilers so that the corrosion would attack them instead of the boiler structure.

It was later discovered that when the temperature exceeded 80°C (176°F), these electrodes reversed their polarity and, instead of protecting, could

attack the iron. Therefore, their use was discontinued.

Sacrificial ZINC anodes wrongly used years ago for corrosión protection,
today MAGNESIUM is better used.

In water heaters with enamelled iron tanks, these sacrificial elements are used, but instead of zinc, they are **magnesium rods. Magnesium provides slightly better protection above 80°C (176°F) in water heaters.**

Without the sacrificial element, if there were a small perforation in the enamel, the tank would perforate more quickly as the current concentrated at a single point, compared to if the tank were unenameled.

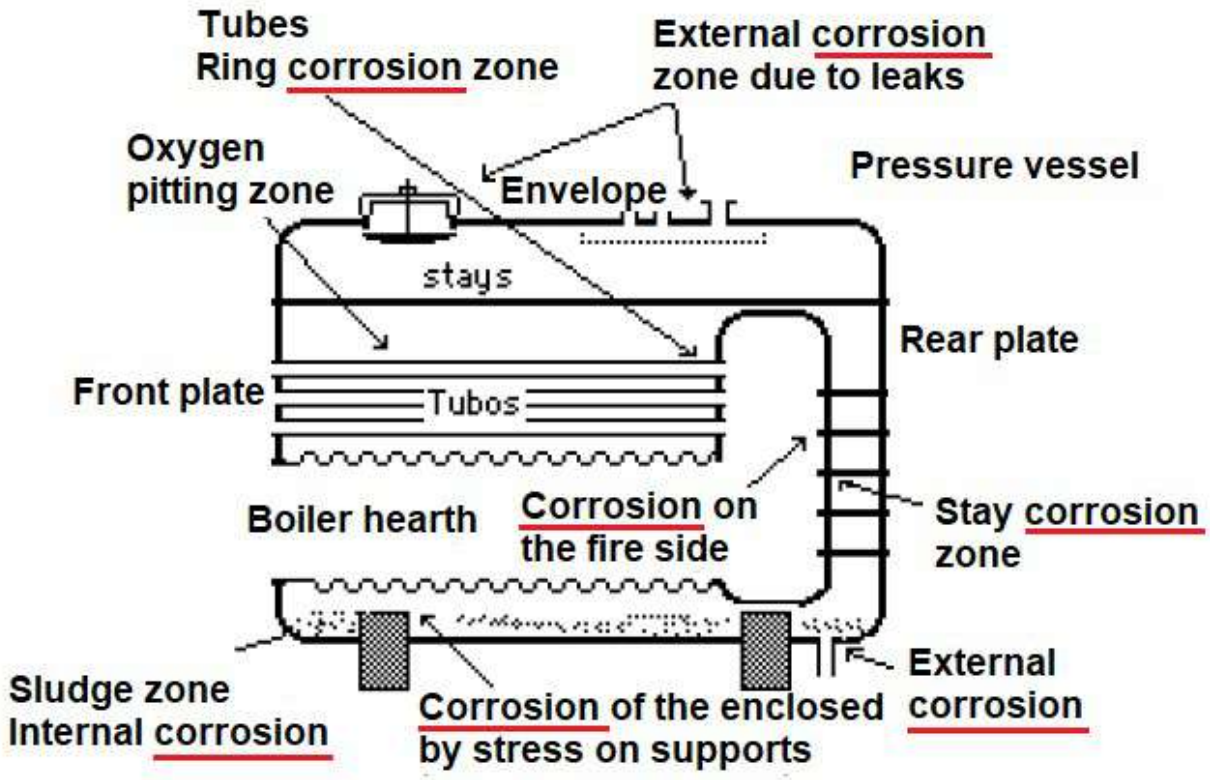
In addition to galvanic currents caused by metal differentials, we must consider others: external currents due to electrical and magnetic losses in electrical installations. **These must be avoided by ensuring proper electrical installation and correct grounding of electrical equipment.**

Other currents that cause corrosion are due to differential oxygen (called "differential aeration"), which is the difference in the amount of oxygen in the water between different parts of the boiler.

This can occur within the same "corrosion cell" -corrosion protrusion- or between a part of the boiler that is "covered with sludge" and the clean part, etc.

In this case as well, internal chemical treatment is essential, eliminating oxygen and preparing the metal surface.

This includes periodic sludge removal or chemical cleaning to eliminate corrosion cells once corrosion has occurred, etc.



POINTS WHERE THE MOST SIGNIFICANT CORROSION OCCURS

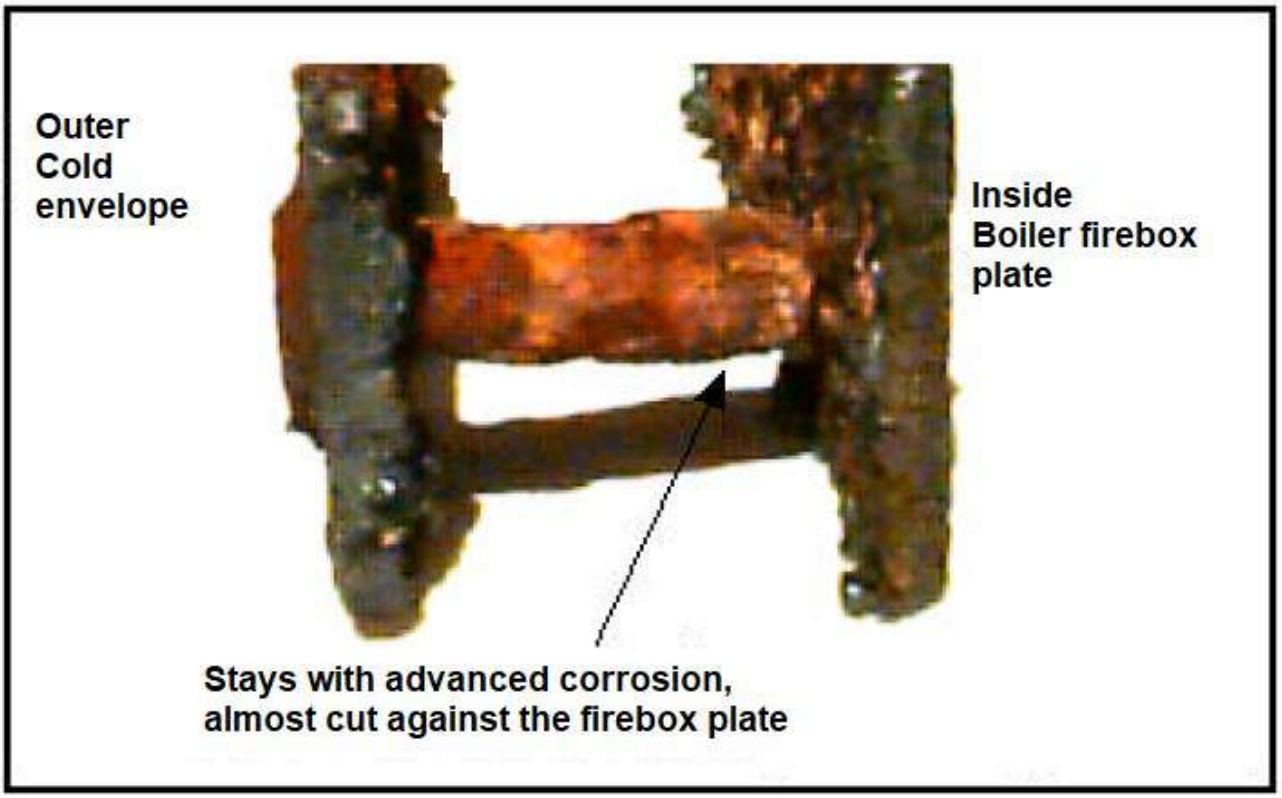
Another instance of this electrical differential: this occurs due to the temperature difference between the metals that make up the boilers.

Here too, potential differences arise that cause corrosion. This case includes the corrosion of the welded stays between the combustion chambers and the shells of some types of fire-tube boilers.

Since the metal of the combustion chamber is much hotter than the metal of the shell (of the pressure vessel, not to be confused with the outer sheet metal that acts as a casing), it produces a voltage difference that creates electrical conduction through the boiler water. This causes corrosion that tends to cut the stays near the hottest area.

This failure is very common in low-pressure heating boilers that have many stays (due to their flat shape) and because their water is not usually chemically treated.

It is important to keep this detail in mind when inspecting boilers of this type: inspection of the "stays" for corrosion against the hottest area.



STAYS SEVERE CORROSION FIRE-TUBE BOILER

In fire-tube boilers, the most common type of corrosion occurs on the tubes, near the "hottest plate" area.

This corrosion is called "ring corrosion," and it is generally attributed to the fact that scale tends not to form on the tubes in this area, which is why it corrodes.

However, it should also be considered that when corrosion is present, scale cannot form on this surface.

With proper internal chemical treatment, this type of corrosion is reduced to a minimum.

Corrosion caused by differences in stress or force on the metal must also be considered in these cases.

These cases are generally found in the areas where the supports or "legs" of fire-tube boilers rest (this also occurs in boilers where a "free" expansion gap has not been left between the support "legs," since for every meter of boiler between legs there is an expansion of 1.2 mm per meter for every 100°C (212°F) increase in temperature).

These areas should be monitored from inside the boiler. In addition to these cases, stresses caused by welds that have not been properly relieved by annealing the boiler must also be considered. Internal chemical treatment is important to reduce their effect.

Softened water, distilled or deionized water, and rainwater: if not properly chemically treated, they accelerate all the types of corrosion we've discussed.

Corrosion in riveted boilers. Although boilers are no longer made with rivets, some riveted boilers (over 50 years old) still exist.

The problem with these boilers is that the rivets "sever" for various reasons, and sometimes this condition (very dangerous) is not visible.

One reason they shear is that they are subjected to two stresses: shear and tensile. This causes rivet fatigue, which is accelerated by the presence of concentrated salts in the boiler water that penetrate the joint, especially what is known as "caustic embrittlement," that is, the presence of large amounts of sodium, which is very common in softened well water.

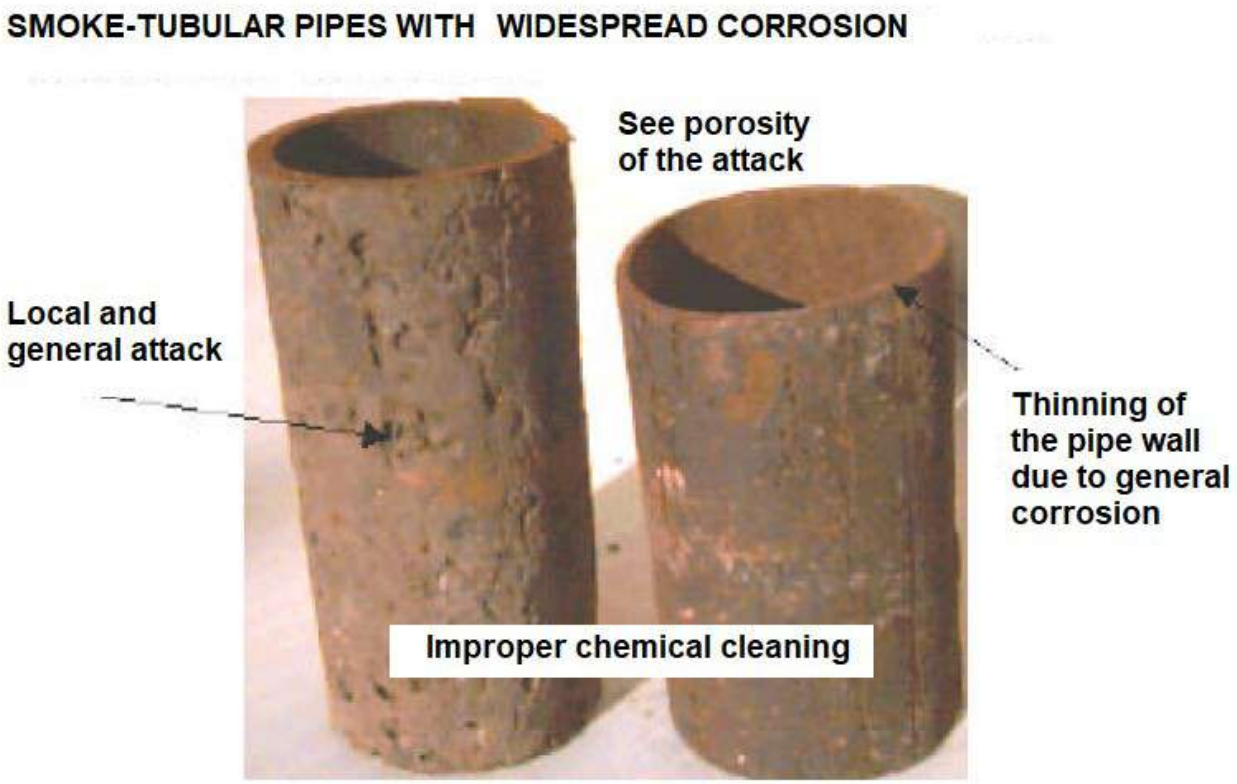
This situation is very dangerous, as the rivets gradually break down and sometimes no leaks appear to "reveal" them (the rust from so many years seals these leaks).

One way to determine this is through non-destructive testing (previously, some rivets were removed to inspect their condition, but since nowadays there are no operators who know how to properly rivet a new rivet in place, much less weld them, this is not a good solution. Non-destructive testing is better.

A "homemade" test involves striking the rivet with a ball-peen hammer (quite forcefully) while the boiler is under hydraulic pressure (working pressure but

100% water pressure, without steam or air inside the boiler to prevent an accident if the riveted joint breaks). If the rivet is cut, it will generally leak water upon impact.

Unfortunately, there is not much awareness of this problem, and sometimes it is advisable to decommission the boiler (which are generally very inefficient, and the cost of a new boiler is quickly offset by fuel savings).


SMOKE-TUBULAR PIPES WITH WIDESPREAD CORROSION
See porosity of the attack
Local and general attack
Thinning of the pipe wall due to general corrosion
Improper chemical cleaning

SMOKE-TUBULAR PIPES WITH WIDESPREAD CORROSION

Generalized Corrosion:

Generalized corrosion generally occurs in the presence of contaminants: acids, organic matter (fats, milk, sugars, etc.) that decompose inside the boiler, forming acids.

Alkaline materials (high hydroxide alkalinity, contamination with sodas, process lyes, etc.) that raise the water's conductivity and pH above 11.5 also contribute. Some improperly used boiler treatment products (bisulfites) or excessively high chemical limits, such as high chloride levels, etc., promote this type of corrosion.

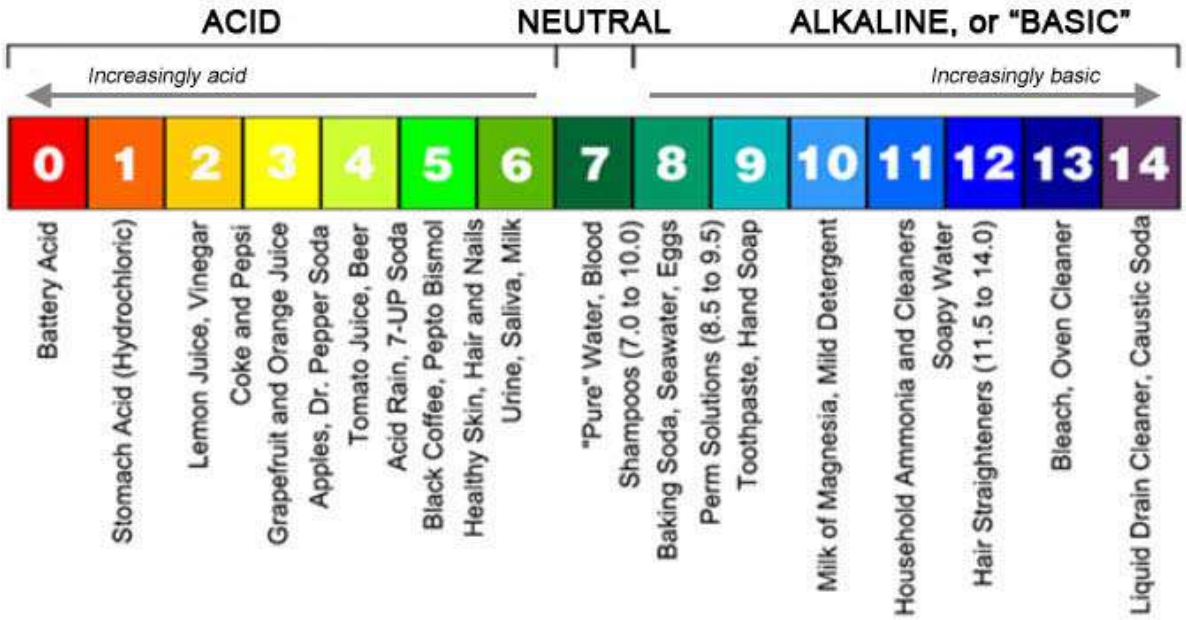
Generalized corrosion can attack the material in the hottest areas (fats, sugars, depending on the fuel used, etc.) or, in some cases, in the coldest areas (chlorides). The corrosion may manifest as direct attack on part of the material or as a failure to form the entire protective oxide layer on the metal surface.

In this latter case, the corrosion is so uniform that it is almost impossible to perceive with the naked eye (e.g., high pH levels: well water with "high alkalinity" softened in a sodium cycle with very high concentrations).

Boiler analyses are essential for detecting contamination.

Establishing the operating limits of the treatment process, as well as the appropriate internal chemical treatment for each feedwater condition, is fundamental.

In plants processing organic matter or contaminants, strict control of boiler water pH must be maintained very regularly (hourly, daily, etc.), since any contamination will immediately affect the pH (very easy to measure with pH paper, which is much more reliable than low- and medium-cost electronic meters, which are very difficult, if not impossible, to calibrate and adjust to their neutral pH point of 7.0).



Monitor condensate for pH, hardness, TDS (Total Disolved Solids), sugars, etc., although some of these contaminants may not affect the TDS or pH of the condensate.

Often, they will be noticeable by the formation of "foam" or rapid changes or fluctuations in levels.

When connecting digesters or other equipment, it is advisable to install check valves to prevent the backflow of contaminants through the steam lines when a vacuum or reduced pressure occurs when the steam is shut off or the boiler is turned off.

In the case of heating highly polluting products, especially those with minimal condensate (such as fuel oil heaters), it is preferable to discard the condensate, as its recovery could cause significant damage if the heating coils rupture.

One particularly important case to consider is the boilers used for heating swimming pool water (whether freshwater or, even worse, saltwater), given that pool water has a high chlorine content for disinfection.

Chlorine in the boiler circuit behaves less effectively than oxygen, which attacks the boiler when it's cold. Chlorine attacks both hot and cold water.

The presence of pool water in the boiler's feed circuit comes from both the condensate return line, due to the rupture of the heat exchangers (which are subject to serious corrosion problems from the pool water and the temperature, which increases corrosion and cracking), and contamination from the steam supply lines themselves.

When the boiler shuts down, it creates a suction effect as it cools below 100°C (212°F). This partial vacuum acts on the heat exchanger, drawing the pool water lost through the steam line into the boiler.

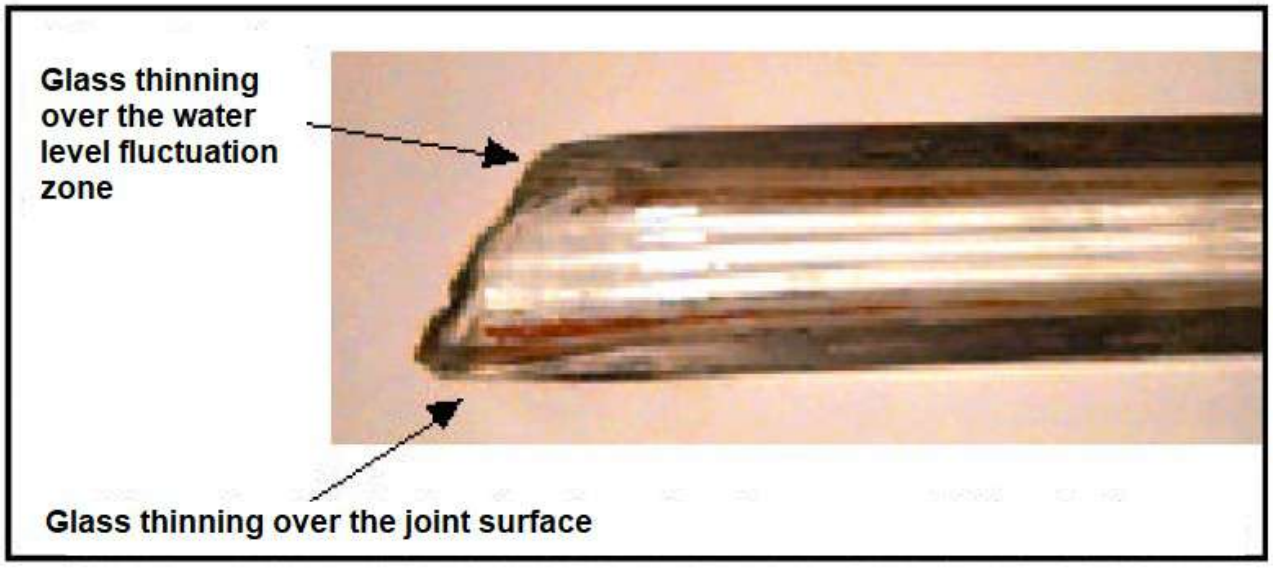
To prevent this, it is advisable to install check valves in the steam supply and also to install a vacuum breaker to prevent negative pressure in the piping.

Often, the heat exchanger loses more heat when it is cold because there is no backpressure on the steam side for the pool water, and cracks can even widen, as in the case of the tube-to-plate joint.

The heat exchanger material must be carefully selected, and the difference in expansion between the tubes and the shell must also be considered, as this is often responsible for the tubes loosening on the plates.

Corrosion on the boiler level gauges:

Corrosion can also occur on the level gauge crystals. This happens as pressure and the free soda content of the boiler water increase.



This problem is very common when using softened well water, due to the high alkalinity, bicarbonates, and sodium carbonates that decompose, leaving free soda in the boiler water and raising the pH to values above 12. Under these conditions, the free soda attacks the crystal, dissolving it in the area where the water level fluctuates, until the crystal breaks.

The solution to this problem is to limit the amount of soda through continuous blowdown or partial removal before feeding the boiler.

The glass panes should be inspected and replaced before they break.

One solution for high-pressure boilers, where the problem is more acute, is to use a mica plate to isolate the boiler water from the glass.

EXTERNAL CORROSION:

EXTERNAL CORROSION ON LEVEL CONTROL CONNECTION PLATE

External corrosion on boilers can be very serious and should be taken into account: it is often the cause of very serious accidents.

External corrosion is difficult to see because it is hidden by thermal insulation. Insulation is not easy to remove for inspection, since once removed it must be replaced.

This often leads to resistance from those in charge, such as the plant manager and other managers, who are reluctant to incur further expenses and costs.

Inspections should be carried out every few years (depending on the age and condition of the boiler) to examine the entire exterior of the boiler (the pressure vessel below the casing or housing).

These corrosive effects can also occur in the fire zone, generally beneath the refractory material or ash.

This can be due to the sulfur in the fuel and its condensation in cold areas, forming sulfuric acid; the condensation of pyroligneous acids in the case of firewood; the presence of acids resulting from incomplete combustion of gases that are not monitored with instruments; undetected water or steam leaks; and other factors.

High-temperature corrosion also occurs in areas where combustion directly affects the material and it cannot be properly cooled or protected.

These areas can include tube ends, welded stay heads, flat headers, or horizontal collectors exposed to fire, tubes or furnaces lacking good circulation, scale buildup, etc.

In some cases, it is necessary to measure thicknesses to assess corrosion, as the loss of metal wall thickness can be very uniform and not noticeable.

Superheaters are highly susceptible to this type of corrosion.

In the exterior area, it is important to consider water or steam leaks onto the boiler casing, due to valves or their fittings, which can seep between the insulation and the casing. This can cause corrosion due to humidity and oxygen in the air, accelerated by temperature.

Therefore, we must inspect the areas surrounding these components. Generally, hydraulic tests do not guarantee safety against an accident caused by external corrosion; these leaks are best monitored visually and by measuring thicknesses once they are located.

All the corrosion we've observed leads us to conclude that boilers that are out of service (shut down) would be better preserved if they were completely dry (using elements that absorb internal humidity or heating to keep them dry) and disconnected from any pipes that could introduce water or steam leaks, or from condensation dripping from roofs or rainwater.

The difficulty lies in the fact that putting this boiler back into service requires several hours of reconnection, filling with treated water, and a hydraulic leak test.

In the case of boilers stored "wet," meaning flooded with chemically treated water, where this method has been used to bring them back into service quickly, care must also be taken to prevent external water from dripping onto the boiler casing or chimney, as external corrosion can be significant during this period.

While heat accelerates corrosion, in this case, because the boiler is cold, the water trapped between the insulation or ash does not evaporate, keeping the wetted parts damp and causing permanent corrosion in these areas.

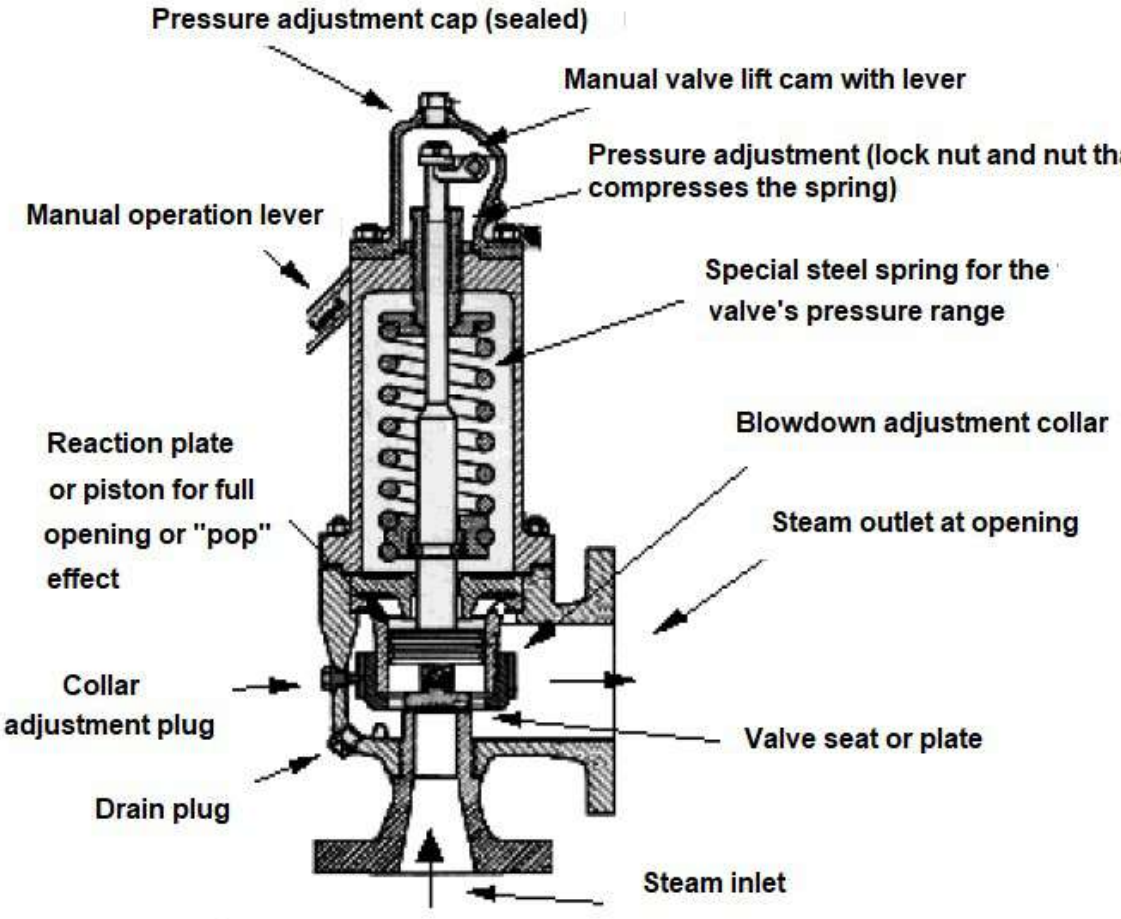
C.W.T. (Carlos W. Thomasset, 1945-2023) serving as chief engineer,
R.O.U. Presidente Oribe,
Uruguay oil tanker bought to Ishikawajima Harima Heavy Industries (1962)

CHAPTER 12: SAFETY VALVES FOR BOILERS.

MINIMUM REQUIREMENTS:

According to American standards, **they must be spring-loaded**.

In Uruguay, safety valves with weights or "counterweights" are not accepted; they are accepted in some European countries, in certain boilers), fully opening (pop effect), close below the opening pressure by a regulated or adjustable percentage (hysteresis or differential closing pressure), and have a lever for testing (weekly, etc.).


Pressure adjustment cap (sealed)
Manual valve lift cam with lever
Pressure adjustment (lock nut and nut that compresses the spring)
Manual operation lever
Special steel spring for the valve's pressure range
Blowdown adjustment collar
Reaction plate or piston for full opening or "pop" effect
Steam outlet at opening
Collar adjustment plug
Valve seat or plate
Drain plug
Steam inlet

These operating conditions for boiler safety valves cause them to open rapidly to full capacity.

This immediate "full opening" is what differentiates a "safety valve" from a "relief valve". The former could be described as having an "all or nothing" opening, while the latter (the relief valve) modulates the percentage of opening.

This prevents the seats from being scored and allows them to reach their maximum discharge capacity immediately.

This ensures that the pressure does not rise above the regulated level for opening, even if the valve's capacity (its large size) allows it.

However, there is a slight pressure increase between the initial opening pressure and full opening, no more than 3% of the initial pressure.

This results in two types of valves: one that opens immediately ("full bore") and another that requires this overpressure or excess pressure to fully open ("low lift").

Closing below the opening pressure prevents the valve from oscillating or rattling upon closing, ensuring a quick closure (this also prevents the seat from being scratched and leaking, and guarantees that the closure occurs below the maximum design pressure).

The lever allows for testing without needing to raise the pressure to the trigger or trigger pressure (the test is performed when the pressure is close to the maximum working pressure, so the effort required to trigger the valve is minimal; this action keeps the valve mechanisms free from seizing, making it important to perform this test periodically (for example, once a week, at times that do not interfere with steam production).

As mentioned in a previous chapter, but reiterated, safety valves should not be painted, as the paint will inevitably affect their mechanisms and operation.

How can you tell if a valve is actually a boiler safety valve once it's installed, and not just a simple relief valve?

Activate the valves one by one, gradually increasing the pressure and taking care not to exceed the maximum permissible working pressure (maximum design pressure or "ringing pressure").

In this case, the valve should open fully (like pulling a cork out of a bottle) and close at a lower pressure (turn off the burner).

If you do not want to raise the pressure above the pressure regulated by the automatic pressure switches, the test can be performed by using the lever: when the maximum working pressure is reached (boiler pressure cutoff).

Pull the lever; the valve will open easily and fully and should close below the opening pressure.

If the valves do not have a test lever, they are already disqualified as boiler safety valves.

These valves are **relief valves for steam, gases, or liquids** (they do not have full opening or differential closing).

When purchasing a boiler safety valve: it generally comes certified by the manufacturer, who has used the original standards.

It is advisable to request the accompanying brochures to check if the valve is approved as a boiler safety valve, and if it has its capacity, opening pressure range, maximum temperature, etc., clearly marked.

This is also important because the materials must be of a quality that prevents the valves from seizing due to corrosion or the seats from wearing down.

The springs are important in terms of material quality (ensuring they do not weaken over time and with temperature) and the range in which they can be used (an overly compressed spring loses travel or length, which reduces the effectiveness of the opening).

For this reason, do not use valves with springs outside the range recommended by the manufacturer. Never replace springs without using those of the quality and characteristics specified by the valve manufacturer.

SAFETY VALVE CAPACITY

It is clear that, from a practical standpoint, the safety valves of a boiler must be capable of releasing at least all the steam generated in the boiler under the most demanding conditions.

For example;
the **burner's automatic high-pressure shut-off could fail, and simultaneously, the mechanism regulating maximum combustion—the high-pressure protection switch—would not shut off**. In a wood-fired boiler, all air vents would open and the induced draft would be set to maximum, or in a fuel-oil boiler, the fuel inlet would be set to maximum along with the necessary air.

The only limit to this maximum is the surface area for heat transfer from combustion to the boiler water and the condition of that surface (fouling).

Another question is what happens if a boiler safety valve becomes stuck or seized (remember that if the combustion limiting mechanisms fail, the only control over the pressure limit is the safety valves; if the only valve we have fails, we obviously run significant risks).

Some standards (ASME, USA) specify the following regarding the capacity of safety valves:

1- All boilers with a heating surface area greater than 500 square feet (approximately 46 m², or 500 kW of power) must have two or more safety valves.

2- The capacity of the safety valves must not allow the pressure to rise above 6% of the maximum allowable working pressure (formerly called the "ringing" pressure) and above 6% of the valve opening pressure.

In German standards, instead of 6%, a 10% excess pressure over the maximum working (design) pressure is permitted.

Similarly, the blowdown pressure in U.S. standards is a maximum of 6% below the opening pressure, while in German standards it is 10%.

However, this blowdown differential (hysteresis) cannot be less than 1 PSI or 2 PSI, depending on the valve's pressure rating, to ensure a tight seal, as described below.

What must be clear is that the closure must be "smooth" (quick) and not "chattering," since not only can the seat be scratched or the valve leak, but it can also cause the valve to oscillate and chatter, potentially leading to its destruction.

The only solution is to gradually increase the closing pressure differential until the valve closes correctly; in some cases, this differential may need to be greater than previously indicated.

This differential adjustment (hysteresis) should supposedly be factory-set and sealed. DO NOT TOUCH IT

It must be clear that the maximum permissible working pressure (boiler design pressure) is not the actual working pressure of the steam supply to the plant.

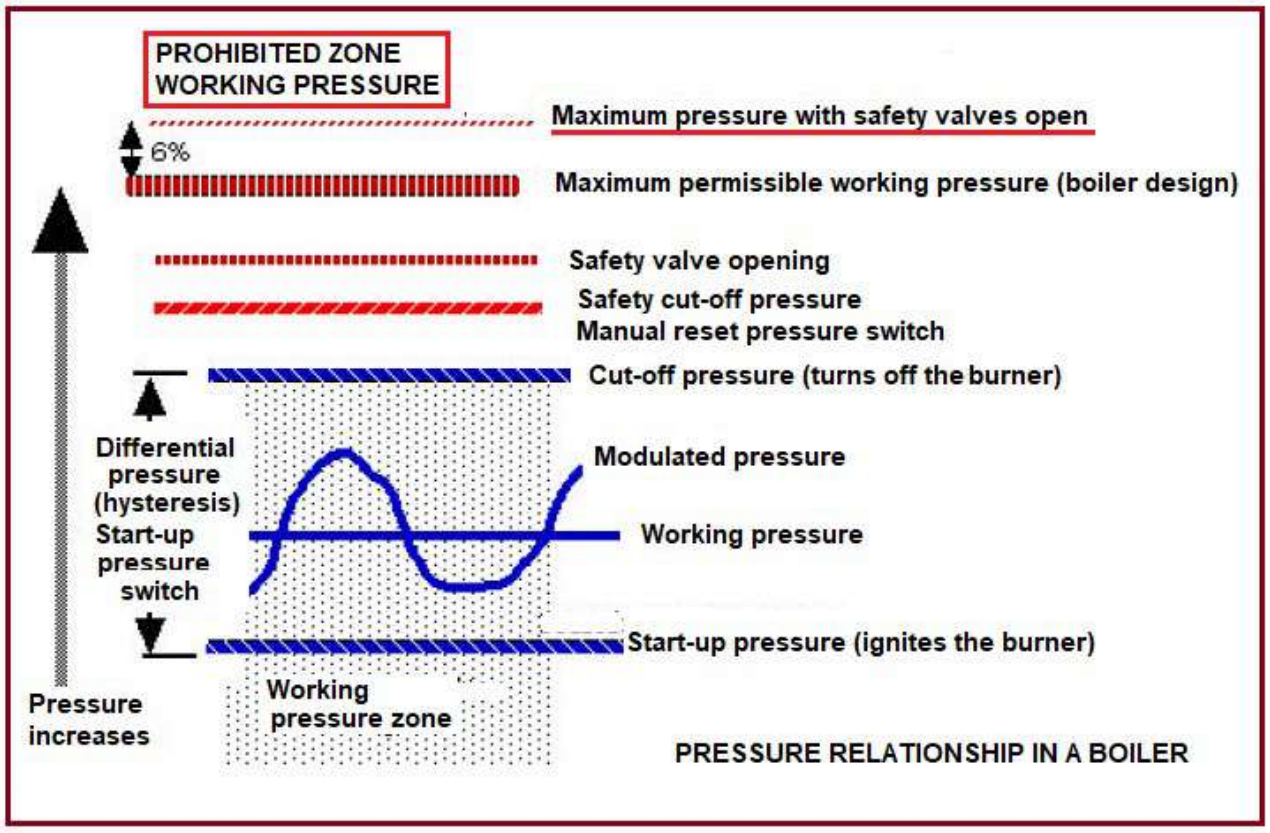
With the safety valves open, under no circumstances (while the boiler is steaming) should the pressure ever exceed 6% (or 10% according to the German standard).

Therefore, the actual operating pressure in the plant must be below the maximum permissible operating pressure (boiler design).

This pressure must be at a level that allows the burner to modulate with the pressure, and above this modulation, a high-pressure combustion cutoff point must be reached (in case the modulating burner, for any reason, allows the pressure to rise to the cutoff limit).

Only above this cutoff pressure will the first safety valve open.

This value may be below the maximum permissible operating pressure (boiler design pressure), but never above it. The pressure cannot be allowed to rise more than 6% (10% in German standards) with all safety valves open.



Between the high-pressure cutoff switch and the opening pressure of the first safety valve, it is advisable to have a maximum safety cutoff pressure switch (with a special pressure switch that opens the circuit and shuts off the burner if the high-pressure cutoff switch fails, but which has the particularity that the circuit does not "close" again unless the boiler operator performs a "reset" or a manual reset button.

In this way, the boiler operator is notified that there is a fault in the pressure control system, meaning that the burner is not shutting off at its normal cutoff pressure, and therefore can investigate the problem before restarting.

Let's look at an example:

We have a boiler whose working pressure should be 10 kg/cm². It's clear that if the burner modulation is continuous, there will be a variation in the regulation that could be approximately plus or minus 0.3 kg/cm² (from 9.7 kg/cm² to 10.3 kg/cm²).

Therefore, there will be a start (and cut-off) pressure switch that could be set to 9.5 kg/cm² (which is regulated by the differential pressure of the start-cut-off pressure switch, meaning that in this case there is a differential set below the cut-off pressure by 1 kg/cm²).

And this high-pressure cut-off pressure switch is set to 10.5 kg/cm² to turn off the burner (set to a difference of 0.2 kg/cm² greater than the highest modulation working pressure variation, or slightly more).

Above the cut-off pressure, it would be advisable to have a maximum cut-off pressure safety switch (with manual reset, but if it is a differential pressure switch and not manually reset, it would be advisable for the differential to be set to the maximum, that is, that the pressure switch does not enable the burner until the pressure drops to a low value, so as to indicate that it has activated the maximum-maximum pressure switch, indicating an abnormality to be checked), which may be about 0.250 Kg/cm2 above the cut-off pressure (10,750 Kg/cm2)

It is evident that the maximum permissible working pressure (design) must be approximately 0.5 kg/cm² above this pressure (the value that could represent the error in the opening of the safety valves).

Therefore, this maximum permissible working pressure (design) must be at least 11.3 kg/cm².

By regulating at least the first safety valve below this pressure and ensuring that all valves are open, the pressure (under no circumstances) should exceed 11.3 x 1.06 (+6%) = 12 kg/cm². Or 11 x 1.10 (+10%) = 12.5 kg/cm² according to German standards.

In practice, we generally ensure that all valves are open before reaching the maximum permissible working pressure (boiler design).

CALCULATING THE CAPACITY OF SAFETY VALVE

There is more than one way to calculate the required capacity of safety valves, some theoretical and others practical.

The first is based on calculating the heat transfer surfaces and the maximum theoretical heat transfer assigned per unit area for each fuel.

For example, this surface is divided into a heating surface and a surface exposed to combustion, and a specific vaporization capacity is assigned to each.

Example:
In a fire-tube boiler burning fuel oil, 39 kg of steam per m²/hour will be assigned to the surface heated by the gases, and 68.3 kg of steam per m²/hour to the surface heated directly by combustion.

Multiplying each surface area by its respective vaporization capacity and adding the results will give us the minimum capacity required for the safety valves.

To this theoretical calculation, practical-theoretical tests can be added. These consist of forcing combustion and measuring the amount of steam. This can be done in two different ways:

1- By measuring the amount of fuel burned per hour and performing calculations based on the fuel's calorific value, the quality of the generated steam (pressure and temperature), and the boiler's efficiency, the amount of steam produced per hour is calculated.

2- By measuring the amount of feedwater per hour and assuming that it will all be converted into steam.

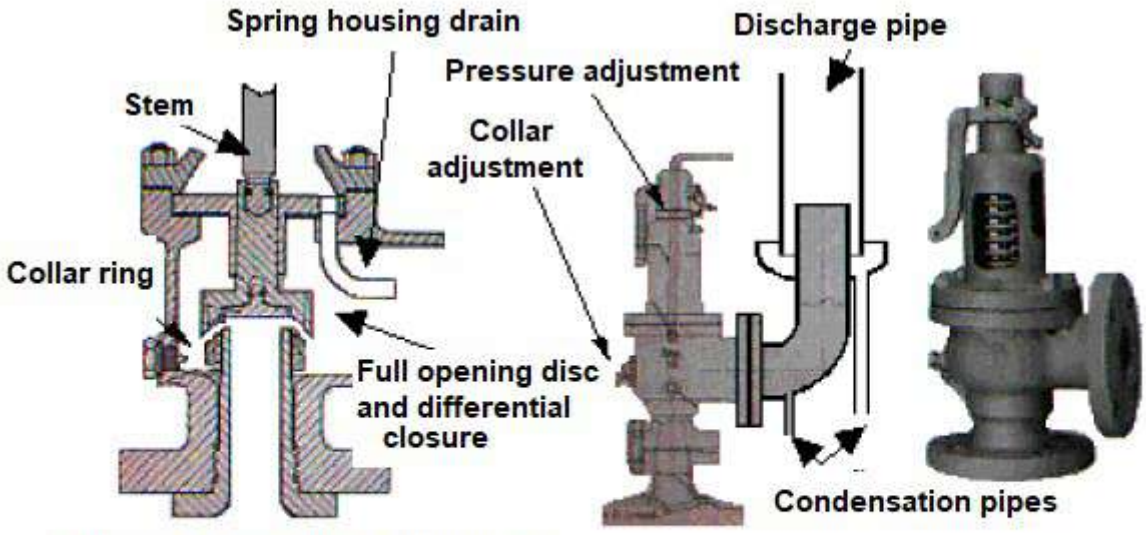
After the valves are installed, it should be verified that, when forced combustion is performed, they do not allow the pressure to rise above the maximum design pressure or "ringing pressure," and that if it does, it does not exceed 6% of that pressure (or 10% if we adhere to German standards).

There are other standards, depending on the country of origin.

The important thing for the stoker is to be certain that the valves are the correct type, size, and material, that they can be tested weekly, if possible, with the lever, and that periodically (at least once a year, with the help of another technician if necessary) they are tested by raising the working pressure to the "ringing" pressure (taking care not to exceed this pressure by more than 6%).

Once the first valve has been tested, proceed to "lock" it and test the second one, which is set to a slightly higher firing pressure than the first.

Remember that in boilers with superheated steam, the superheater safety valve (specially designed for high temperatures) must open before the others and close last, ensuring continuous steam circulation in the superheater (otherwise it will "burn out" due to the high temperature).


Spring housing drain
Discharge pipe
Pressure adjustment
Stem
Collar adjustment
Collar ring
Full opening disc and differential closure
Condensation pipes
Full opening and differential closure depend on the collar adjustment
Safety valve installation
The opening pressure depends on the tension of the spring pushing the stem

The valve discharges should be installed as freely as possible, avoiding elbows or branches, maintaining the correct pipe cross-section, keeping them short, and securely fastened.

It is important to prevent condensation from flowing back towards the valves by directing the drain towards the outlet and installing drains where necessary (almost always against the valve and preventing the drain from falling onto the boiler by using a pipe to divert it away from the casing).

Poor installation of the safety valve discharge piping can limit the capacity needed to prevent the pressure from exceeding the maximum tolerable pressure (6% above the maximum allowable working pressure (design)), which is why actual discharge tests are very important.

C.W.T. Carlos Walter Thomasset (3rd left stand) serving in oil tank R.O.U. Presidente Oribe

CHAPTER 13: PACKINGS AND GASKETS

Packings and gaskets are elements used to "seal" or prevent the loss of fluids (liquids, gases, vapor, etc.) that are at a higher or lower pressure (vacuum) than that of the medium surrounding the product to be confined.

The materials used can be quite varied, taking into account the pressure they must withstand, the temperature, mechanical stress, chemical attack from the fluids, product contamination, etc.

For example, the packing for a pump for acid (e.g., sulfuric acid) is not the same as that for an alkali (e.g., soda ash), the pump shaft speed (300 rpm or 2800 rpm), etc.

A gasket in a steam pipe operating at 10 kg/cm² must withstand approximately 183°C (361°F), but if the steam were superheated to 340°C (644°F), the thermal conditions would be different, etc.

The installation and tightening of both gaskets and packings are also important.

A wide gasket, for the same tightening torque, compresses less than a narrow gasket (because the pressure is greater in the narrow gasket due to the smaller surface area: P = F/S).

A plate should be tightened in a crisscross pattern so that the force is evenly distributed to maintain the plate's parallelism.

A packing should be tightened considering the type of lubrication used: whether it is lubricated by the loss of the fluid itself (in the case of water, there should be a small loss that serves as lubrication and cooling, generally one to two drops per second) or whether there is an external lubricating and cooling fluid (which, in addition to preventing the loss of the fluid being sealed to the outside, can still allow some fluid to enter the sealed fluid).

Gaskets are currently being replaced by mechanical seals, and gaskets by "gasket formers" based on pastes or elements that tend to harden with temperature, oxygen in the air or lack thereof, or the mixture of two products (epoxy type).

Let's look at some of the most common problems and their solutions**:**
"Man entry" joints, "head entry" joints, "hand entry" joints:

For low pressures (less than 15 kg/cm²), they are generally made of braided asbestos (a type of asbestos that is silkier, with long, flexible fibers), like a folded cloth forming a ring, or already shaped to the elliptical or oval form of the gasket seat and sewn at the joint ("glued" with paste and graphite).

They come with flaked graphite on their outer surface to prevent sticking and improve sliding (lubrication) when tightened.

To order it, you must provide the diameter measurements of the ellipse (OVAL type gasket, the larger and smaller diameters).

Before removing the cover, it is advisable to "break the vacuum" (cool the boiler below 60ºC 140°F), ensuring that nothing falls inside the boiler (sometimes it is advisable to weld a ring or washer onto the covers to attach a safety wire or cable).

Remove the bridge and tap it with a mallet with a wooden block on one side of the cover (carefully!).

To install it, the gasket seat on the inlet cover and the gasket seat on the casing must be properly cleaned (by scraping and brushing well, but avoiding removing material from the seat or scratching it, as it will be damaged and lost; if the seat is in bad condition, it must be "filled" and properly resurfaced).

Once the seats are clean, the gasket is mounted on the lid and inserted into the boiler, tightened by hand with the bridge nuts (after brushing and lubricating the threads with graphite flakes using heavy oil, gear oil, or grease).

Then, alternately tighten the nuts mounted on washers with a long-handled wrench.

Once pressure builds up, the gasket must be retightened very carefully.

This is because the gasket weakens with the temperature and internal pressure of the boiler.

A manhole has a surface area of approximately 1000 cm² and a pressure of 10 kg/cm². This means a tightening force of 10 tons (10,000 kgf) is required when the boiler is pressurized.

When the boiler shuts down, this force is lost, and the pressure is instead pushed out by the vacuum created by the condensation of the steam, allowing the gasket to loosen and leak.

A gasket should never be left leaking, as this can affect the seal and the moisture from the leak will cause corrosion.

When the pressure exceeds 15 kg/cm² (213 PSI), the use of prefabricated gaskets with a backing material may be advisable.

Gaskets with inserts or mesh are suitable for boilers with pressures up to 21 kg/cm² (299 PSI). For higher pressures, spiral-wound gaskets or gaskets lined with copper or bronze, such as those used in automotive cylinder heads, are recommended.

These gaskets must also be carefully installed and retightened, following the supplier's instructions. The use of sealing compounds should be considered in some cases, and the use of graphite may not be advisable when the gasket could cause corrosion of the seat (in the case of spiral-wound stainless steel gaskets, galvanic corrosion occurs that "eats away" at the iron seat of the boiler and the lid).

Graphite or special greases are also used in these cases for the threads.

When it is necessary to perform high-pressure hydraulic tests (strength tests), the gaskets must be replaced after the test.

Sometimes it is advisable to use gaskets made of less expensive materials that can withstand the pressure (the temperature will be ambient) for the test, and then the correct gaskets will be installed.

Again, do not leave the gaskets in place for extended periods; the seats will become scratched, and the cover or the gasket seat will corrode.

When the pressure exceeds 15 kg/cm² (213 PSI), the use of prefabricated gaskets with backing material may be advisable (with inserts or mesh, this up to 21 kg/cm² (298 PSI). At higher pressures, spiral-wound gaskets or gaskets lined with copper or bronze, such as automotive cylinder head gaskets.

These gaskets must also be carefully installed and retightened, following the supplier's instructions. The use of sealing compounds should be considered in some cases.

Graphite may not be advisable when the gasket could cause corrosion of the seat (as in the case of stainless steel spiral-wound gaskets, galvanic corrosion occurs, which corrodes the iron seat of the boiler and the iron of the lid).

Graphite or special greases are also used for the threads in these cases. When high-pressure hydraulic testing (strength testing) is required, **the gaskets must be replaced after the boiler's hydraulic test.**

Sometimes it is advisable to use gaskets made of less expensive, pressure-resistant materials for the hydraulic test (at ambient temperature), and then install the correct, high-quality gaskets.

It is reiterated, do not leave the gaskets with leaks; wasting a lot of time will "scratch" the seats and corrode the lid or the seat of the casing.

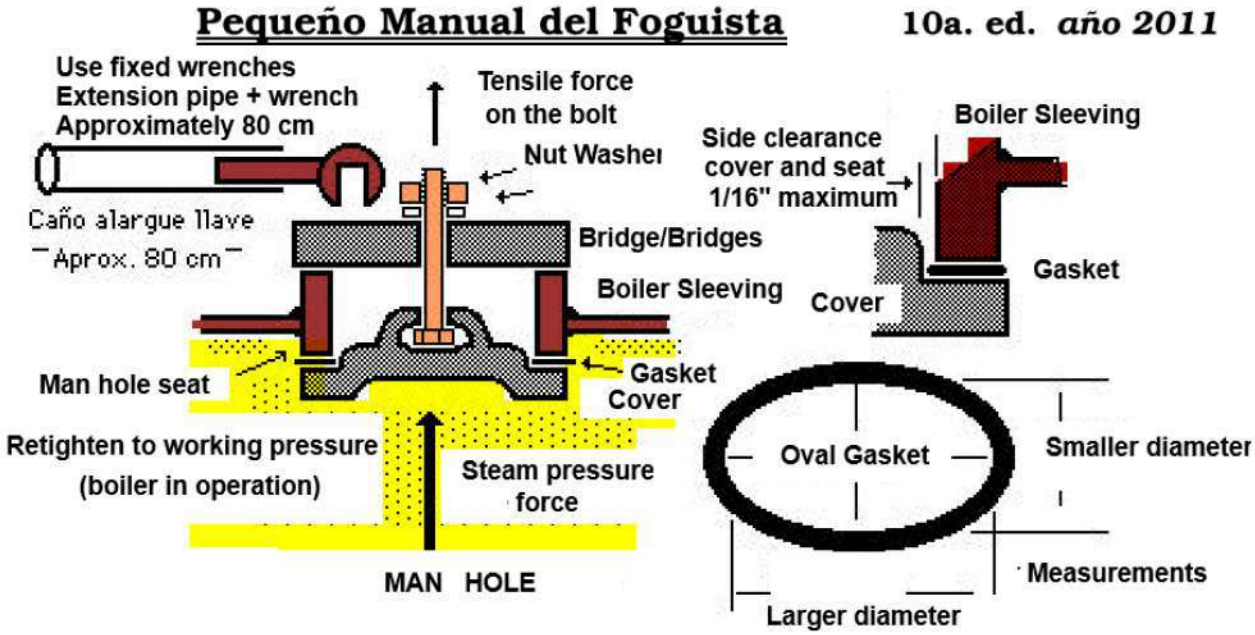


Plate Gaskets

In this case, the pressures for using flange or plate gaskets in the steam piping of the industrial plant must also be considered. At low pressures, gaskets generally need to be cut from sheets of varying thicknesses.

The appropriate gasket thickness is the thinnest that the seat finish allows (the more perfect the seat surface, the thinner the gasket can be and the better its seal).

As pressure and temperature increase, the gasket may contain higher-temperature materials and metal inserts that improve its pressure resistance (wire mesh, metal shavings, etc., up to preformed spiral-wound gaskets, used in high pressure and temperature applications).

The gasket must be cut correctly, so that it occupies the surface where the sealing area meets (by trying to make a gasket that is too large, the pressure of the screws is distributed and the sealing pressure on the gasket is poor, not tightening well and allowing leakage).

Thoroughly clean the surfaces to be sealed on the plate (including any grooves), and apply sealant and lubricant if necessary.

If the gasket is no longer graphite-coated, this can be prepared graphite flakes or another product purchased for this purpose. However, graphite should not be used when the gaskets are made of precious metal, nor with spiral wound gaskets under high pressure, as graphite can cause corrosion on the seat.

In this case, only the surfaces in contact with the gasket should be thoroughly cleaned.

Check the alignment of the valve seats. Clean and lubricate (graphite or other lubricant) the bolt threads. Tighten evenly and alternately as you would tighten the cylinder head of an automotive engine (the tightening torque will depend on the pressure plate, the appropriate quality of the bolts, which are generally rated according to the fluid pressure and specified by the plate).

The plates are standardized according to their intended use: pressure and temperature, pipe diameter, etc., generally by Series 150-300-600-900 or PN 10-16-25-40, etc., or the applicable standards.

The plates should not be retightened without first shutting off the fluid or steam they carry, taking great care not to overtighten the bolts, which will weaken them (a torque wrench can be used).

As an example, we can say that: a 1/2" bolt with 13 threads per inch has a maximum torque of 4 kg-m (kilograms per meter, meaning that on a 1-meter lever, a force of 4 kilograms translates to a tightening force of 1820 kgf per bolt); a 5/8" bolt with 10 threads/inch has a torque of 8 kg-m, etc. This torque depends on the quality of the bolts.

The finer the thread pitch, the greater the force for the same torque.

Tightening the nuts on the bolts of a flange/pipe plate joint under pressure can result in a serious accident if the bolts break.

As an emergency sealant, in case the surfaces are damaged, and which also works for threads, you can make the following: Boil linseed oil until it thickens to a cool, honey-like consistency. Take one measure of graphite flakes and one measure of red lead powder (adjusting the amount depending on the quantity used, as it hardens). Mix with the linseed oil until you reach a desired paste consistency. Apply to both sides of the joints and press firmly. (This paste will dry and seal, but can be removed when necessary.)

Do not confuse this with litharge (glycerin and litharge), which is widely used at low temperatures and as a sealant for various difficult-to-seal fluids, such as fuels, oils, coolants, etc.

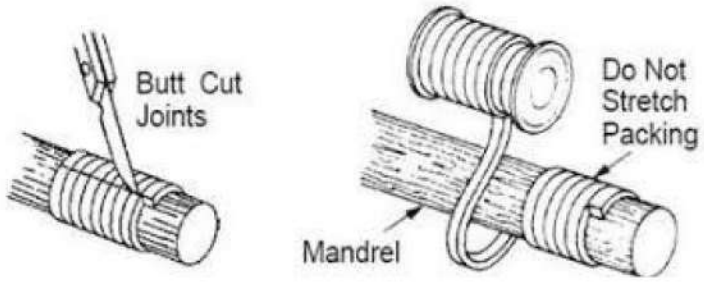
As a rule of thumb for the use of gaskets, a manufacturer has established that they can be used up to the numerical limit that comes from multiplying the pressure in PSI by the service temperature in degrees Fahrenheit (°F):

Material	Maximum Pressure x Temperature	Max. Temperature °F
Rubber	15,000	300
Vegetable Fibers	40,000	250
Solid Teflon	75,000	500
Rubbed Asbestos Cloth	125,000	400
Compressed Asbestos	250,000	850
Types of Metal	above 250,000	Tmax. (F) depends on metal

PACKINGS:

These are used to seal valve stems, pump shafts, etc. The material varies widely, with asbestos (now banned), Teflon, and graphite (synthetic) still commonly used. They can come as pastes, but are generally sold as cords or tape. The installation technique differs between pump shaft and valve packing.

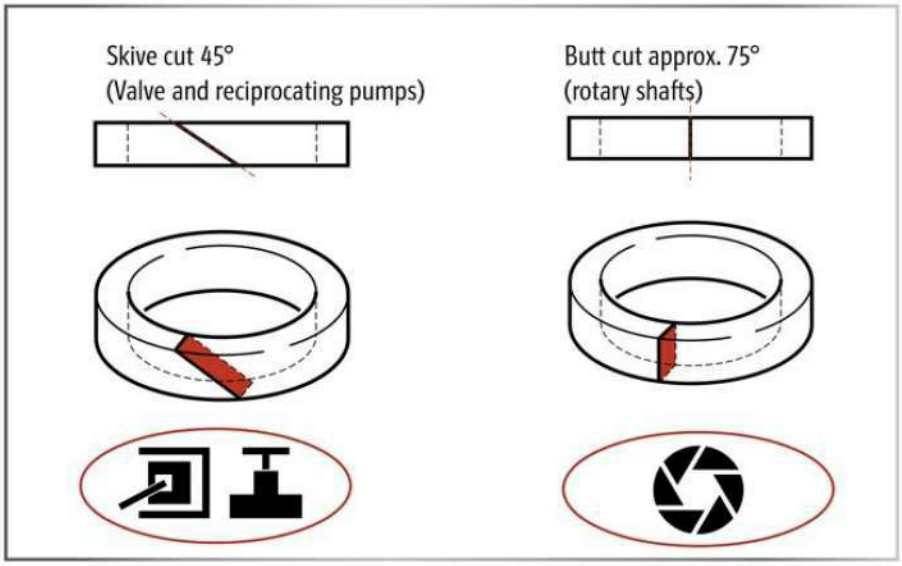
To cut the packing, depending on whether it's for a pump or a valve, you must take a piece of pipe or shaft with the same diameter as the pump shaft or valve stem.



(Packing stretch and cut, SOURCE: https://practicalmaintenance.net/)

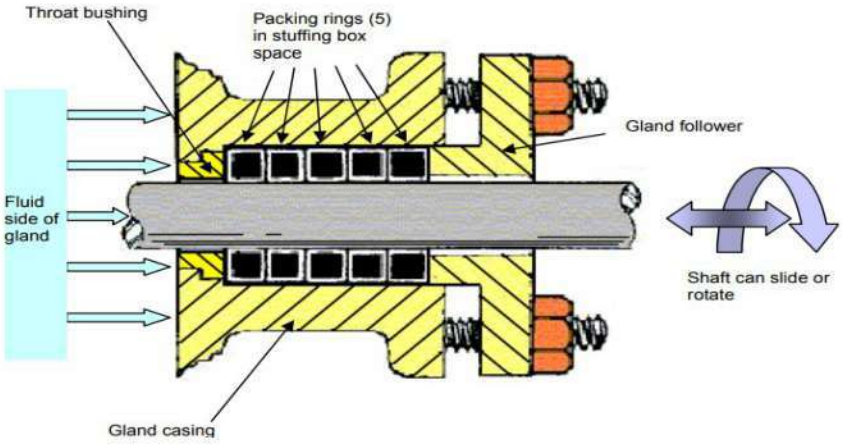
Let's wrap a few turns of the packing roll around the "shaft" and cut the packing with a very sharp knife.

For pumps, the cut will be straight (a longitudinal cut along the center of the shaft, so that when the packing gland is tightened, the packing compresses slightly against the shaft and housing, elastically, allowing the shaft to rotate and be lubricated by the fluid being sealed or the auxiliary lubricant.



(Packing cut 45° for axial movement, or straight for rotary shafts, SOURCE: https://www.propack.ag/)

This should lose one to two drops per second, preferably more at the beginning). For a valve, the cut will be at a 45° angle (a 45° cut relative to the shaft, so that when the packing gland is tightened, it tends to close around the shaft and housing, blocking the fluid passage).



(Packing rings and Gland, SOURCE: https://automationforum.co/)

When installing the gaskets, the cuts should be evenly spaced along the circumference (remove the old gasket completely using a corkscrew or a steel wire with a hook).

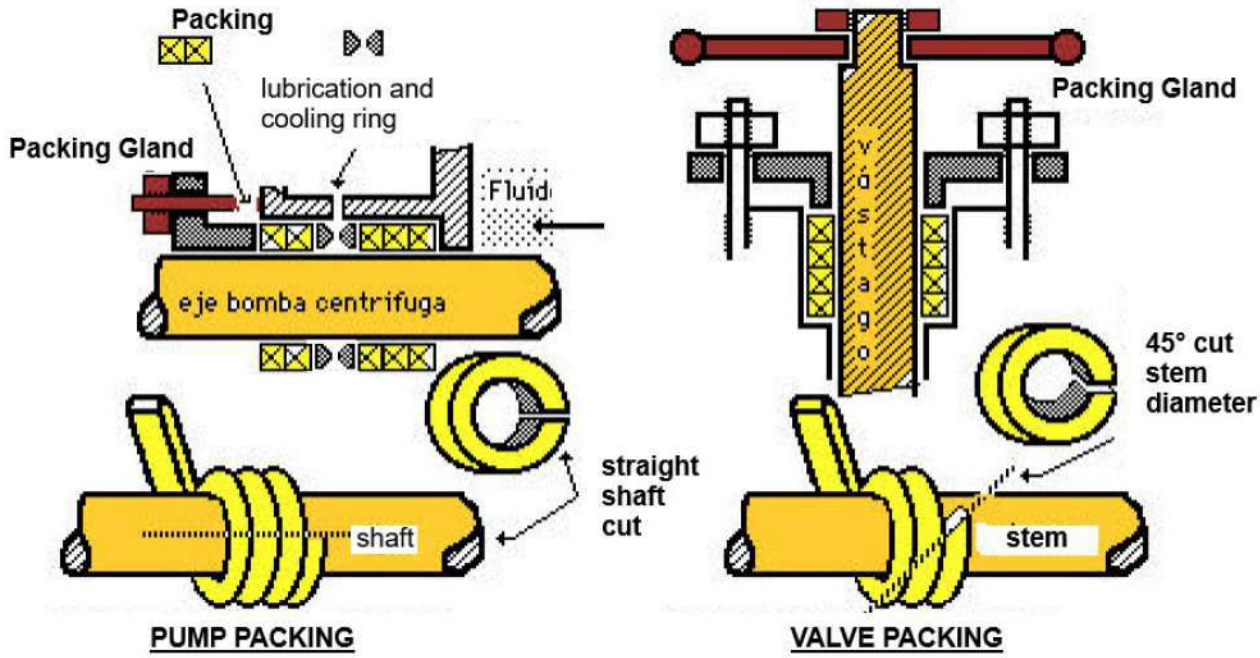
Do not overtighten the packing gland at first; it's better to let it leak a little more and tighten it gradually (tightening the nuts gradually and evenly).

As a general rule, never start a pump without the fluid to be pumped or without opening the seal and packing lubrication valve, since lack of lubrication will not only cause the packing to "burn" but can also damage the pump's internal wear rings.

Centrifugal pumps should also be started with the discharge valve closed when their power exceeds 10 HP; that is, start them without a load, but "flooded."

The valves on some equipment, such as refrigeration (ammonia) systems, should have their clamps loosened to maneuver the valve and then retightened once the valve is in position. This prevents leaks.

When a pump or valve seal starts leaking too quickly, it's time to repair either the pump shaft or the valve stem (which may be bent, misaligned, or scored).



In some cases, pumps have a wear sleeve that can be resurfaced or replaced. Otherwise, the shaft will need to be rebuilt (without warping it) and reground (in some cases, this can be done with cold-applied hard chrome plating followed by reground).

In other cases, a new shaft must be manufactured from the appropriate material (especially if corrosion is present).

Asbestos is a material whose fibers should be avoided, as inhaling them can cause cancerous lesions. Its use is being phased out for this reason. It is already banned in some countries, especially "blue" asbestos, which was widely used in thermal and acoustic insulation.

THREADED JOINTS:

Threaded joints in pipes (pipe threads generally have a taper that causes the "male" thread to tighten against the "female" thread) still require some type of sealant to prevent fluid loss between the threads.

This sealant will also depend on the temperature and the type of fluid (water, steam, naphtha, fuel oil, etc.).

Nowadays, materials such as Teflon tape and Teflon paste are used. Also very good are those prepared with: white lead or red lead powder with annealed linseed oil, litharge with glycerin, or, in cold water, a "filastic"

solution with slightly hardened paint remnants, etc.

Care should be taken not to use pastes containing flammable elements in oxygen pipes. Litharge with water or Teflon suitable for this application should be used instead.

There are other commercially prepared products; the manufacturer indicates the correct way to use them.

Litharge (yellowish): lead oxide PbO; White lead: basic lead carbonate used as a white pigment;

Minium (red): lead oxide Pb3O4...all these lead derivatives are poisonous.

Glycerin: obtained as a byproduct of oils and fats; do not use it in oxygen.

Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 13: PACKINGS AND GASKETS

The Stoker Boiler Handbook ("Pequeño Manual del Foguista" in spanish) by C.W.T.
was written thanks to Apple Mcintosh computers series, first one the 128K owned by CWT in 1984

CHAPTER 14: FIREWOOD DRYING

The moisture content of firewood is expressed (in the case of its use in boilers) as Wet Basis = %Hbh (percent moisture content on a wet basis).

Therefore, when measuring moisture, a quantity of firewood is weighed at its moisture content (Ph) and dried to a constant weight (Ps).

To calculate %Hbh, the formula is:

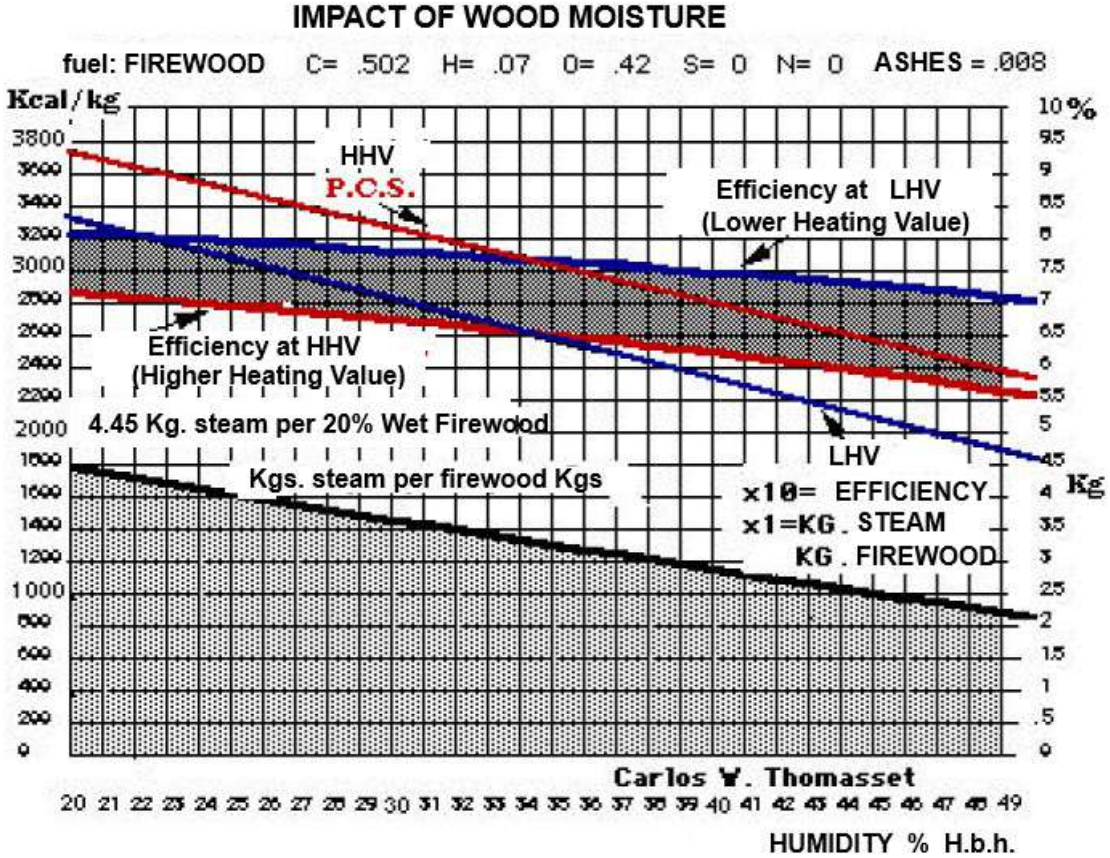
%Hbh = [(Ph - Ps) / Ph] x 100 = (% Moisture content on a wet basis).

If firewood is purchased based on a specific moisture content, to calculate the "equivalent" value (in energy value, i.e., its equivalent to dry weight: Ps) from weight A to weight B, the following calculation can be used:

PhB = (1- %HbhA/100) x PhA / (1-%HbhB/100)

%HbhA = % Moisture content on wet basis of weight A
%HbhB = % Moisture content on wet basis of weight B
PhA = Wet weight A, PhB = Wet weight B to be calculated.

Let's look at the importance of the moisture content of firewood (expressed on a wet basis) in the values related to steam generation.



In the graph above (with the calorific value in kilocalories on the left, the ordinate on the x10 axis representing efficiencies, and the kilograms of steam per kilogram of wood on the x1 axis, and the moisture content of the wood on a wet basis (Hbh) on the abscissa),

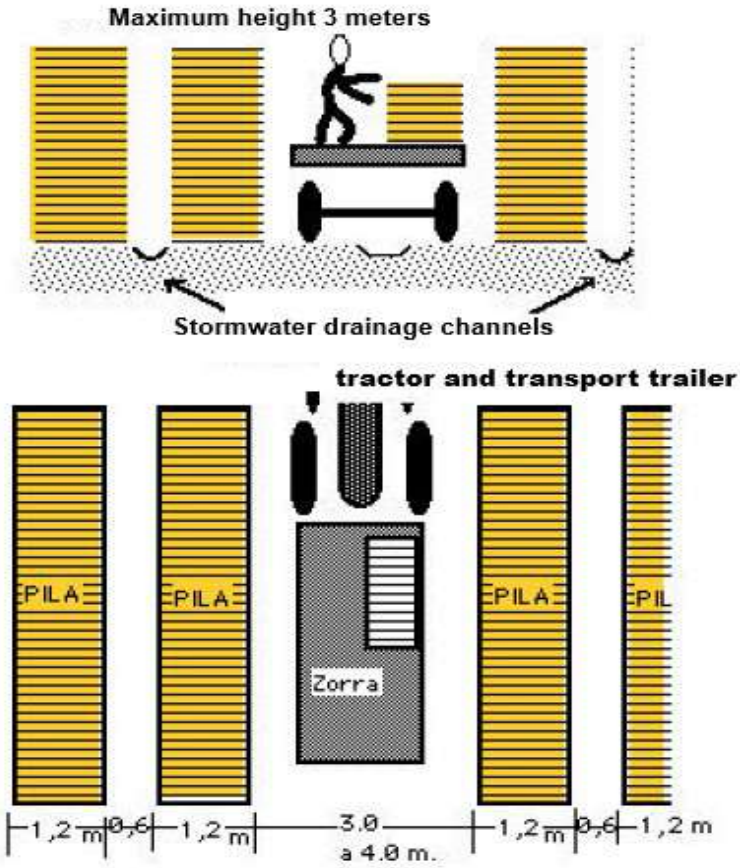
Hbh = percent moisture content on a wet basis

We see that with wood moisture content between 20% Hbh and 49% Hbh, the calorific value decreases in a downward curve (with the lower heating value decreasing further due to the increased moisture content), which in turn causes the efficiency to also decrease.

This is further reflected in the fact that with a moisture content of 20% HB, 4.45 kg of steam are produced per kg of wood,

but when the moisture content increases to 49% Hbh, only about 2.25 kg of steam can be produced per kg of wood.

We have assumed that the excess air is twice the moisture content (%) and that the boiler is operating with values that have remained constant, except for the excess air.



Arrangement of eucalyptus logs for drying.

Proper firewood drying is crucial, as improper storage can result not only in inadequate drying (the moisture content doesn't decrease within the expected timeframe), but also in various types of losses: biological decay ("burning," "fermentation," etc.), loss of volatile compounds ("distillation"), insect damage, and so on.

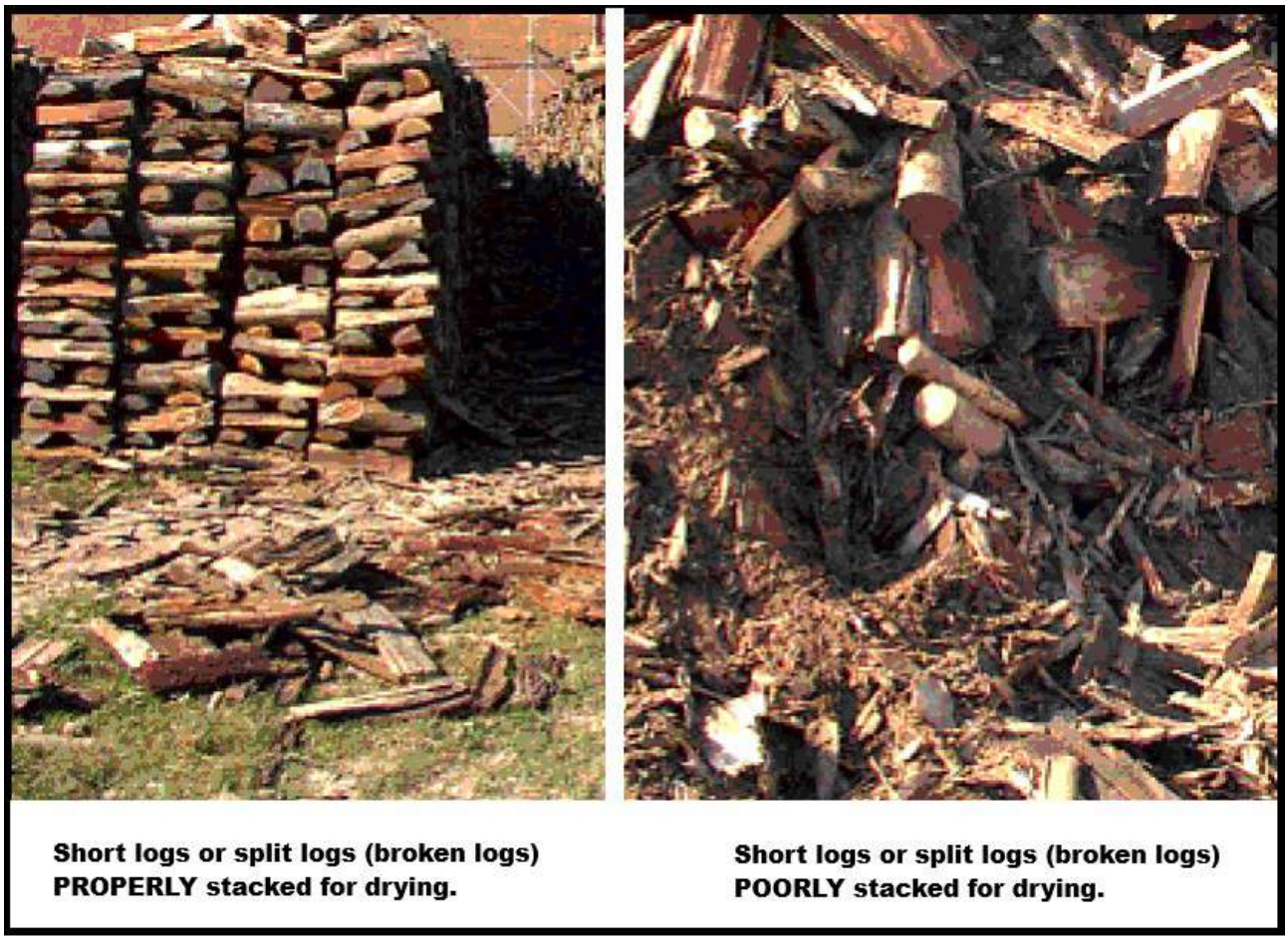
Due to all these factors, firewood should be dried as quickly and under optimal conditions as possible to minimize losses. To achieve this, it is advisable to follow the guidelines outlined above and below.

Winds are essential for drying firewood, as an air current dries it more effectively than direct sunlight (only the wood at the top receives direct sunlight).

Therefore, we must arrange the stacks in an orientation that allows the prevailing winds to pass through the interior of the logs and stacks.

Similarly, we must drain the entire storage area to prevent rainwater from accumulating. Weeds should be kept out of the stacks by using a weed killer or by cleaning them regularly. It's also advisable to use an effective insecticide to eliminate wood-boring insects (the use of these products should be discussed with an agronomist).

Arrangement of the piles of firewood with respect to the prevailing winds throughout the year and land slide rain water draining.



Short logs or split logs (broken logs) PROPERLY stacked for drying.

Short logs or split logs (broken logs) POORLY stacked for drying.

Firewood should not be piled up in a way that prevents air circulation (such as when it is dumped from trucks, either manually or using the truck's tipper). Keep the drying area clear of trees both around its perimeter and within its boundaries. Losses can be as high as 30% or more of the calorific value of firewood dried under good conditions.

See CHAPTER 5: Operation Part 6 for more detail on safe an unsafe woodfire loaders.

CHAPTER 15: THE SUPERHEATER

Superheated steam is saturated steam that has been "superheated".

Saturated steam, steam that is in contact with the water that produces it, both at the same temperature and pressure, in equilibrium, the steam may have moisture, but it cannot have a temperature higher than that of the water that produces it, see saturated steam tables.

If saturated steam is moist, to begin superheating it will first receive heat, evaporating the moisture or "droplets," maintaining the same temperature until it becomes "dry" saturated steam.

This "dry" saturated steam is then heated above its saturation temperature as it passes through a zone where it receives more heat, which does not increase its pressure but does increase its temperature.

For example:
steam at 10 kg/cm² (142 PSI) is saturated at a temperature of 183°C (361°F).

If this steam receives more heat by passing through a zone with a higher temperature, its temperature will rise above 183°C (361°F), but its **pressure will neither rise nor fall from 10 kg/cm² (142 PSI)** unless it is compressed or there is a pressure drop.

We can say that saturated steam can be wet or dry (without water droplets), while superheated steam is dry steam, and its behavior is similar to that of gases.

What is superheated steam used for?

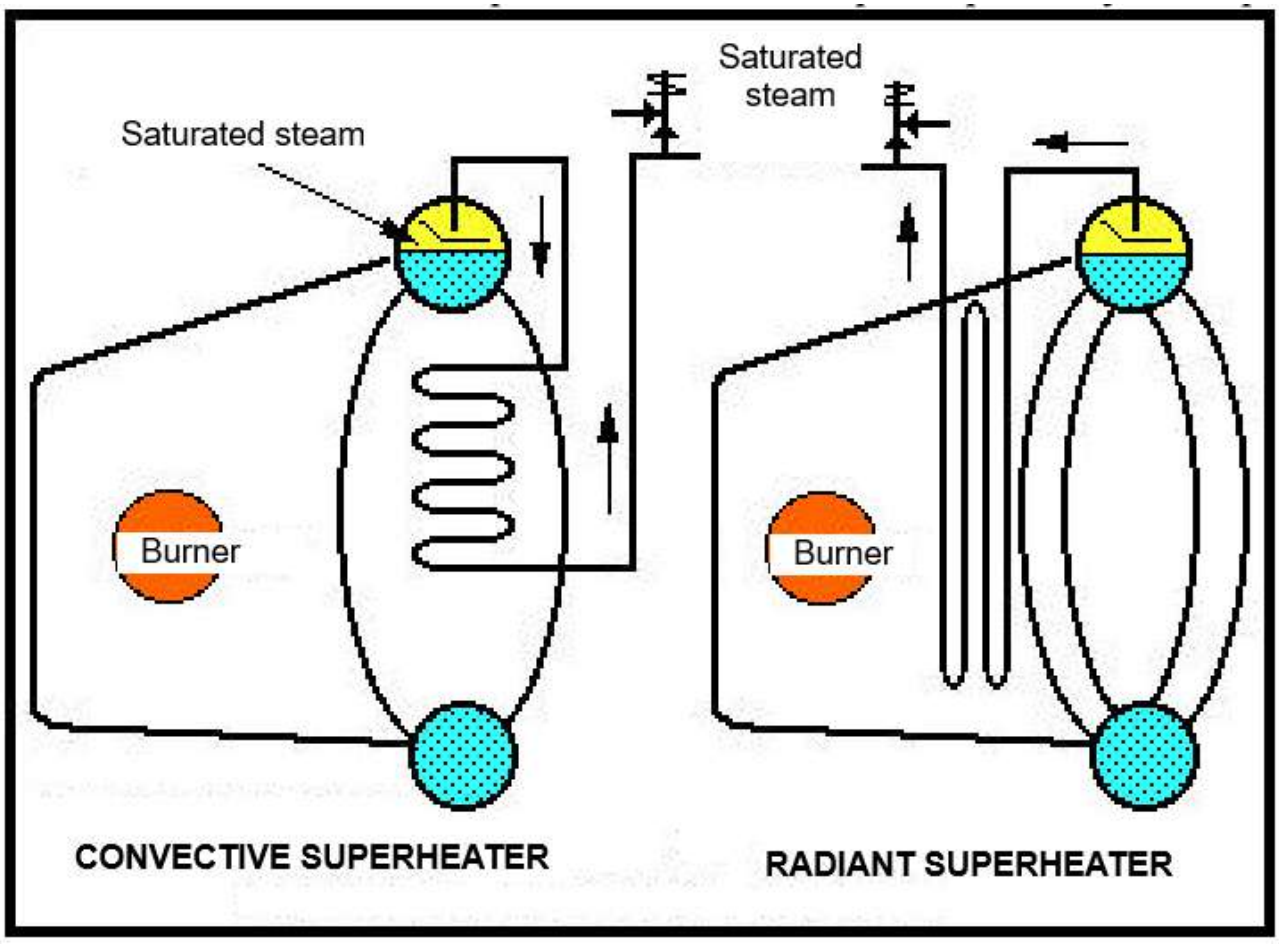
When it is necessary to operate a steam turbine, if saturated steam were used, droplets would form in the steam as it cools.

Steam Turbine Rotor Blades, SOURCE: wikipedia

At the speed at which the steam drives the turbine blades, these droplets would act like pellets, breaking the metal upon impact with the blades.

It is also used in some steam transport applications or steam engines to ensure that the steam arrives dry (without droplets or moisture).

Superheated steam is not ideal for heat transfer because it tends to behave like gases (which require a larger heat transfer surface, hence the finned design of gas or air heat exchangers). Tables are available for superheated steam, providing its characteristic values based on pressure and temperature.



INTEGRATED SUPERHEATERS

Superheaters are generally justified in power generation boilers (where turbines drive machines or electric generators, or power a ship's propulsion).

Therefore, they are generally installed in water-tube boilers because medium and high pressures are used, as they are not feasible in fire-tube boilers due to the pressure and large capacities required.

However, some fire-tube boilers may have a small superheater (usually in the smoke box) for minor steam superheating for transport or special use.

This superheating is around 15°C to 50°C (59°F to 122°F) and not much more, whereas in water-tube boilers the superheating can reach hundreds of degrees Celsius, even exceeding 300°C (572°F) in some cases.

In the case of fire-tube boilers, the superheaters are integral to the boiler (that is, they are always in the boiler's steam and flue gas circuits).

Their superheat is determined by the design, and the boiler operator has very little control over the superheat.

In water-tube boilers, the superheater can be integral, separate, or partially separate from the main combustion flow or influence.

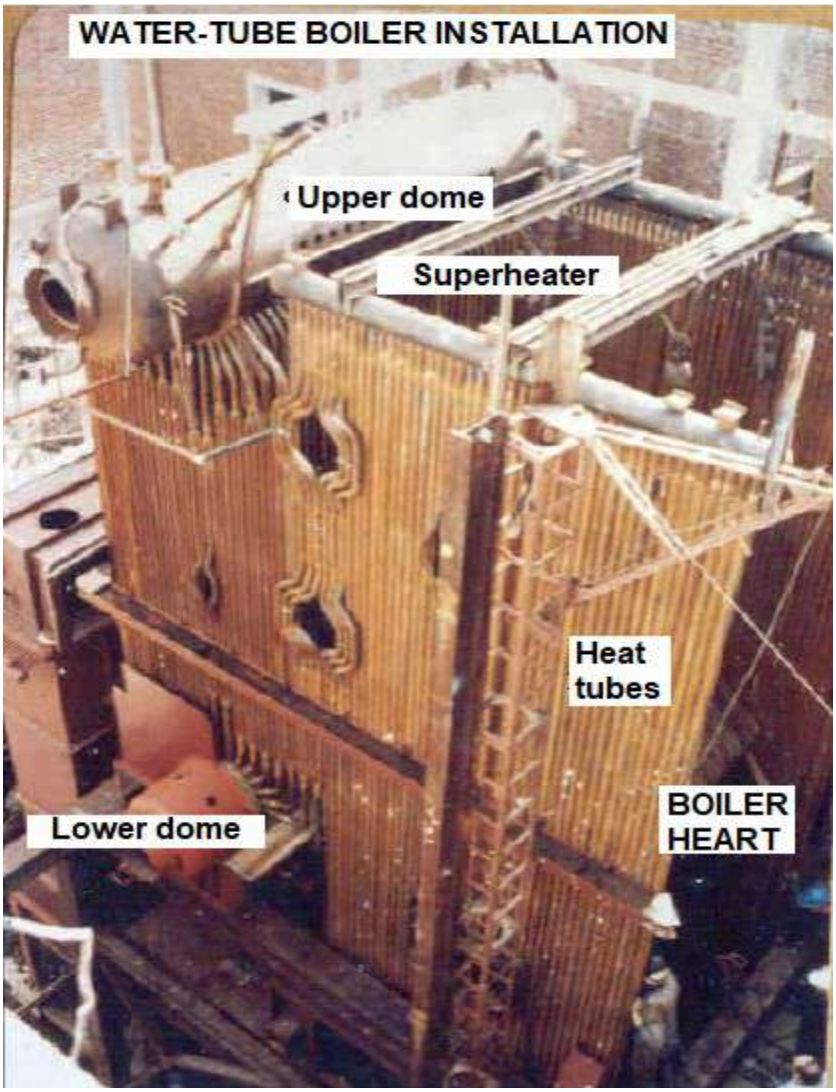
If the superheater is separate or partially separate, the temperature can be regulated by the operator, taking combustion into account. In the superheater area, there is a burner designed for this purpose, or baffles that direct the flue gas flow.

When the superheater is integral, the variation lies in its position relative to the boiler's combustion (that is, depending on its position, it will be a superheater influenced by direct exposure to combustion, "radiant," meaning exposed to the radiation of the main flame; or only influenced by the passage of gases, in which case it will have a screen of boiler tubes that protects it from combustion radiation, "convective," since it is protected from the radiant heat of the flame).

A superheater can have a mixed characteristic, meaning that without being entirely radiant, it has some exposure to flame radiation.

Excess air and the use of cold water feed tend to increase the superheating temperature, etc., all of which lower the boiler's efficiency.

In the integral superheater, the steam temperature can be regulated by injecting water (demineralized or pure condensate; never use water containing anything other than pure water) or by bypassing it to a tube cooler inside a water dome of the boiler itself.



What are the most significant problems with superheaters?

I believe we should discuss at least three, especially regarding integral superheaters:

The first is starting up a boiler with a superheater without "burning out the superheater," that is, without exceeding the temperature of the metal.

While superheaters up to relatively low temperatures (approximately 400°C - 752°F) are made of the same material as the boiler, when operating at higher temperatures they are made of more refractory materials (iron with elements such as chromium, nickel, molybdenum, etc., which are more resistant to high temperatures).

STARTING UP BOILERS WITH SUPERHEATER

All superheaters have the problem of startup, since at this stage the boiler gases (which are at a high temperature) and the fact that steam is not circulating inside the superheater (meaning the tubes are subjected to the temperature of the gases or the radiant flame), and also because at this start-up stage the steam has a low density (kg/m³), meaning that although there may be a volume flow, at this stage the mass flow or weight is not very high and the steam temperature can "spike" due to a lack of cooling mass.

It should be noted that these superheaters can also be divided into floodable superheaters (which can be filled with water for startup) and
non-floodable superheaters (which cannot be flooded for startup, making them more vulnerable to "burning out" at this stage).

Ideally, the boiler should be started with auxiliary steam circulation from another boiler, so as not to leave the boiler's heating stage dry.

In any case, the "start-up" or heating process must be very slow, venting steam to the atmosphere to maintain a cooling steam circulation, whether from auxiliary steam or steam generated within the boiler itself, with very close monitoring of the superheater temperature.

Then, the steam will be transferred to the consumption system, and the steam valve to the atmosphere will be closed in a coordinated manner.

If the superheater is floodable and there is no auxiliary steam, it is advisable to flood the superheater with demineralized water or pure condensate (never boiler water, since the evaporation of the salts will leave the superheater walls scaled with dry salts each time it is started).

But if the superheater is not floodable, greater care must be taken during the start-up (very gently), always venting steam to the atmosphere.

The superheater should NEVER be left without steam circulation while the boiler is lit or when high-temperature gases are present (as when shutting down a boiler with a large amount of refractory material).

As mentioned previously, the boiler's safety valves are regulated so that the superheater valve opens first (and generally has a significant steam release capacity to prevent overheating) and closes last.

This also applies when shutting down the boiler; never close the superheater steam valve before extinguishing the fires.

Even allow a slight vent to the atmosphere for a few minutes after extinguishing the fires to monitor the superheater metal temperature.

WATER CARRYOVER

The second point regarding the superheater is: under no circumstances should water carryover be allowed in the boiler.

Boiler **water carryover** contains salts that deposit in the superheater (and also affect the turbines), insulating the metal from the cooling effect caused by the passage of superheated steam.

This causes the metal's temperature to rise above what it can withstand, and the superheater "burns out."

Carryovers are generally due to: excessive momentary steam consumption in the industrial plant, pH issues, excess free soda, the presence of surfactant contaminants, high TDS (Total Dissolved Solids), or insoluble salts, etc.

One situation that can cause boiler water carryover is when there is a drop in boiler pressure (due to momentary excessive consumption, a combustion problem, etc.).

When the pressure drops, the specific volume of the steam increases dramatically (its density or specific weight decreases). In other words, the same weight of steam (its consumption in kg/hour) increases in volume.

For example, saturated steam at 40 kg/cm² (569 PSI) occupies 0.049 m³/kg. If the pressure drops to 30 kg/cm² (427 PSI), its volume increases to 0.066 m³/kg, a 34% increase.

This volume increase creates two unfavorable conditions that cause carryover: first, the boiler level rises (the steam decompresses within the water where it forms, increasing the volume of bubbles, like a carbonated beverage when it's opened); and second, the velocity of the steam at the interface between the steam and the water increases (which makes separation difficult and promotes entrainment).

These boiler water carryovers not only tend to scale the superheater, but also affect the steam turbines (the impact of water droplets on the turbine blades causes erosion and scaling that unbalances the turbine, causes vibrations/noise, and reduces turbine efficiency by affecting the nozzle passages and altering the surfaces of the turbine blades).

In the event of a significant pressure drop, stop the turbine!

The third point regarding the superheater is its maintenance when the boiler is out of service.

It must be maintained under the same conditions as the rest of the boiler: flooded with treated water to prevent oxygen corrosion, with a pH no lower than 10.5, and with a hydraulic seal to absorb the water's expansion due to ambient temperature variations and prevent air (oxygen) ingress.

Of course, there are other problems to consider in the superheater: as high-temperature gas-side corrosion.

The effect of vanadium contained in the fuel oil, ash erosion from burning coal or cellulose fuels, attack by some salts, especially potassium salts in biomass, etc.

And low-temperature corrosion when the boiler is out of service, generally caused by sulfur and ambient humidity (this is corrected with indirect heating).

The issue of chemical cleaning must also be considered.

When superheaters are specialized, acids that could damage these metals should not be used.

For example, hydrochloric acid, one of the most important chemical cleaning agents, especially due to its effectiveness and cost, damages high-temperature superheaters that contain chromium and nickel alloys.

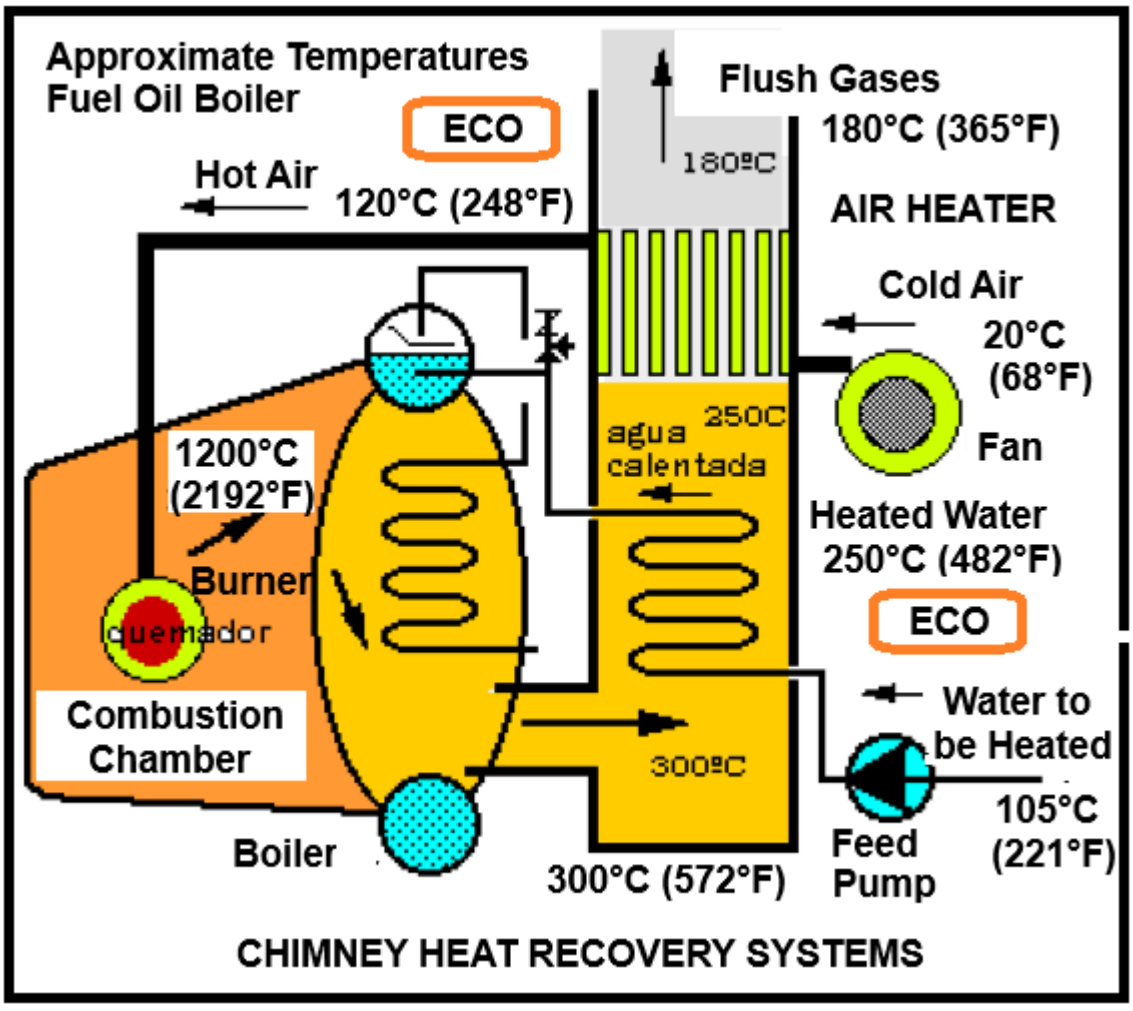
C.W.T. (Carlos Walter Thomasset writting first version
of the STOKER BOILER HANDBOOK (“Pequeño Manual del Foguista”),
Apple Macintosh 128K computer,
first one sold in Uruguay by Martin Ponce de Leon to C.W.T. year 1984

CHAPTER 16: HEAT RECOVERY SYSTEMS
THE AIR HEATER AND THE ECONOMIZER

Heat recovery from flue gases is done to improve the utilization of heat that would otherwise be lost. Generally, the gases exiting the last pass of the boiler, regardless of the fuel, are at a temperature
50°C (122°F) to 100°C (212°F) higher than the saturated steam in the boiler.

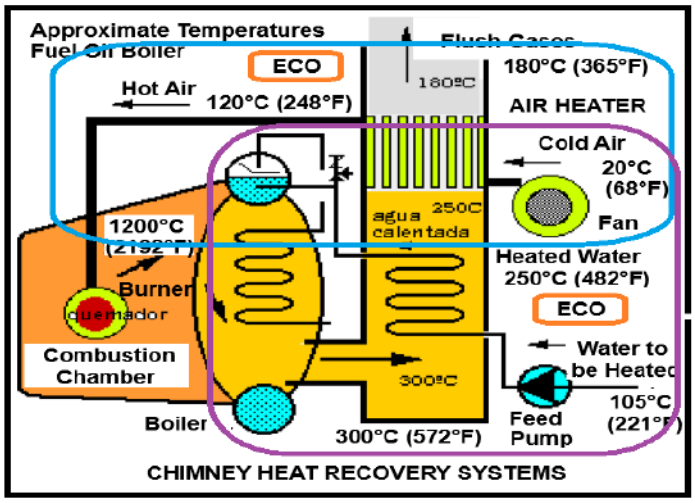
Since the boiler has a heat exchange limit (which depends not only on the heat transfer surface area but also on the available temperature difference, i.e., the temperature difference between the combustion gases and the saturation temperature at the boiler's operating pressure).

This means that beyond a certain point, increasing the boiler's heat transfer surface area is either not feasible or not economically viable.
Therefore, heat recovery systems must be used, which utilize fluids at a lower temperature than the water inside the boiler.



These low-temperature fluids can be:

The relatively cool feedwater (the economizer or "ECO") or the air used for combustion (the air heater, which improves combustion conditions, especially when burning wood in logs).



Although other fluids could be heated for different uses, provided the temperature difference allows it.

Heat recovery in a boiler's chimney improves performance or efficiency to a significant degree, which can vary depending on local conditions, boiler type, and fuel type (this recovery can generally range from 3% to 10%).

In the case of the economizer (ECO, boiler feedwater heater), there are two problems to address: internal corrosion and scaling (the water must be chemically treated) and the problem of external corrosion or corrosion in the flue gas zone.

With the sulfur in the fuel, it forms SO2 and SO3, which then form sulfuric acid with the moisture from the water produced during combustion (oxygen, when it combines with hydrogen, forms H2O, or water).

This type of corrosion will occur in both the ECO and the air heater if the gas temperature drops to the dew point.

This is the temperature to which the gases must be lowered to form water droplets; this temperature will be higher as the amount of sulfur in the fuel and the amount of water in the gases increase, as well as the amount of "unburned" gases, usually "pyroligneous" acids - acetic, formic, etc.).

To prevent sulfur corrosion in both the ECO and the air heater, the water or air will have to be preheated to avoid areas where the temperature of the metal on the gas side reaches or drops to the dew point.

For example:
in general when working with heavy F. Oil which contains a lot of sulfur, the minimum temperature in the gases should be no less than 180ºC (356°F).

This sulfur problem continues to attack the iron components during shutdowns because acid remains in the ash, refractory materials, or deposits that may form in the areas of the heat exchangers and air heaters.

During extended shutdowns, it is advisable to wash both heat exchangers with hot water slightly alkalized with soda and then dry them with indirect heat. Maintain a dry atmosphere during the shutdown, using heat or another method, but never leave them damp after washing.

Additionally, it is advisable to close the outside air circulation by sealing the chimney to prevent the entry of humid air.

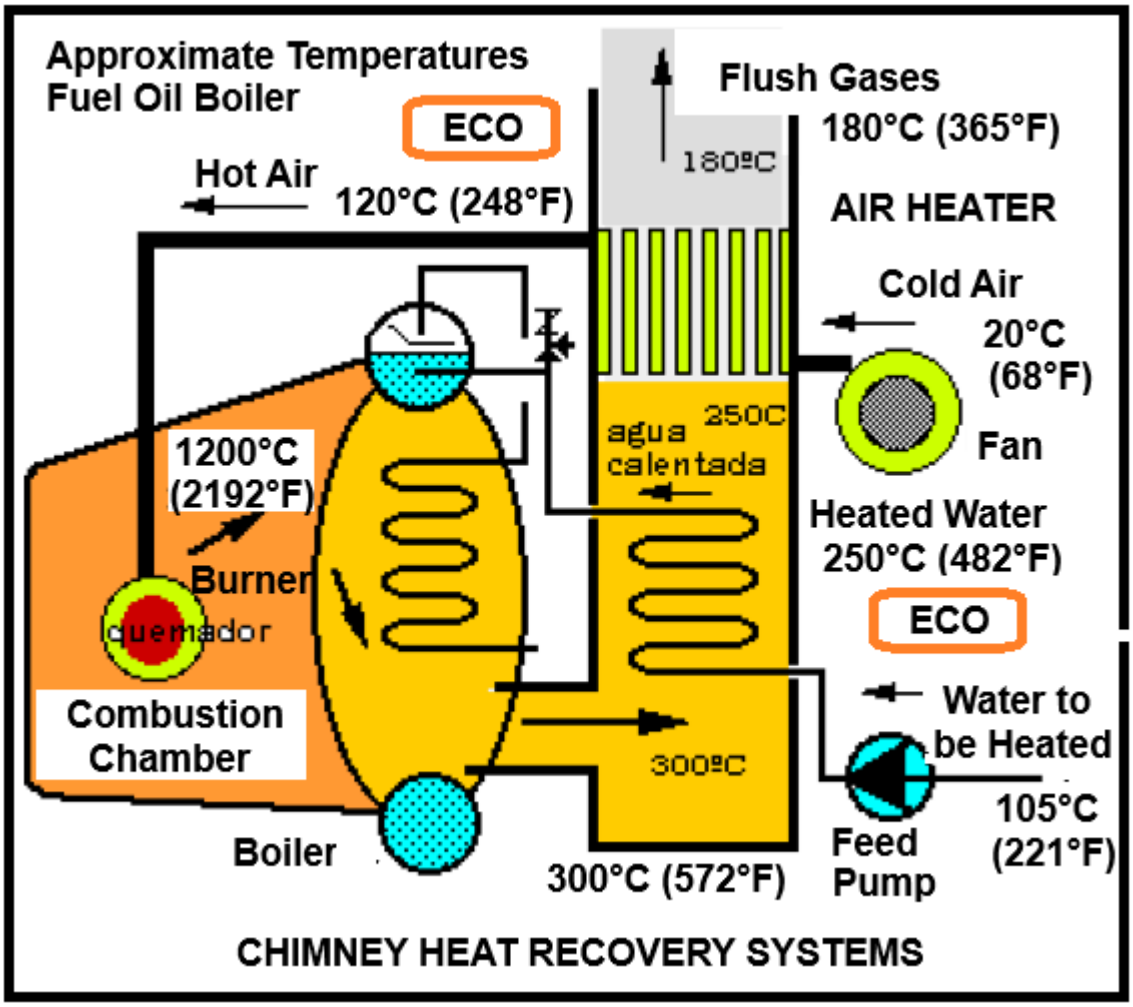
This entire corrosion problem has led to the creation of ECOS and air heaters made of more corrosion-resistant materials (even glass has been used in air heaters).

These high-quality materials perform well, but they still require cleaning on the flue side.

This is because some fuels (except natural gas and other gases that burn cleanly without producing soot) deposit soot or ash in these relatively cooler areas, causing poor heat exchange and hindering gas flow.

In the ECOS, this problem is exacerbated, especially when they are finned on the flue side to increase the heat exchange surface, since the heat transfer coefficient on the flue side is lower than on the water side.

One way to clean these exchangers, in some cases, may be the use of hot water (creates a problem of acidic effluents in F. Oil), during a momentary stop, otherwise in other cases soot blowers with steam or compressed air may be implemented (creates a momentary contamination at the gas outlet).



With some "clean" burning fuels, free of sulfur or other contaminants (such as soot, ash, etc.), as is the case with some gases (with good combustion, no soot, and no unburned gases), it's possible to utilize even the latent heat of the water present as steam in the gas stream (for this, the gases are "scrubbed," and this water, which has accumulated latent and sensible heat, is exchanged).

In industry, the challenge lies in finding sources of energy utilization at low temperatures (such as heating water for industrial use, space heating, or other applications), which isn't always easy to find, since there are other losses at higher temperatures (such as steam condensate, its "flash," which is surplus and has no application since process temperatures are sometimes higher).

The other problem to consider is that if the flue gases are excessively cooled, they will not rise on their own, which leads to environmental pollution near the

flue gas discharge area.

In economizers (ECOs), water circulation must be continuous and upward (to prevent the formation of "steam pockets").

If the feed is on and off (intermittent), the stagnant water in the ECO will vaporize, causing corrosion, salt deposits, and excessive metal temperature with oxidation.

This can result in slow and even "rapid" combustion. The latter, fueled by the backflow between the steam and the metal of the ECO, can generate so much heat that it melts the ECO. It should not be extinguished with water; in fact, ships have sunk when the boiler and its containment material melt, perforating the ship's hull.

Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 16: AIR HEATER AND ECONOMIZER

C.W.T. a man of challenges
Hundreds of steam boilers in Uruguay have borne witness to this.
This Stoker Boiler Handbook series reflects this by describing practical experiences.

CHAPTER 17: BOILER WATER PREPARATION Part 1

Boiler water preparation, once "clarification," "filtration," etc., has been carried out (in well water, this is generally not necessary, except for sand removal; in OSE water or purchased supply, it is also not necessary, but if the water is from the surface and is taken in natural conditions, it must be treated to make the water "clean" enough for industrial use, not necessarily potable).

However, this water, depending on its chemical values (TSD, Total Hardness, silica, etc.), and depending on the type of boiler, pressure, steam quality, etc., will require treatment to make it suitable for its intended use.

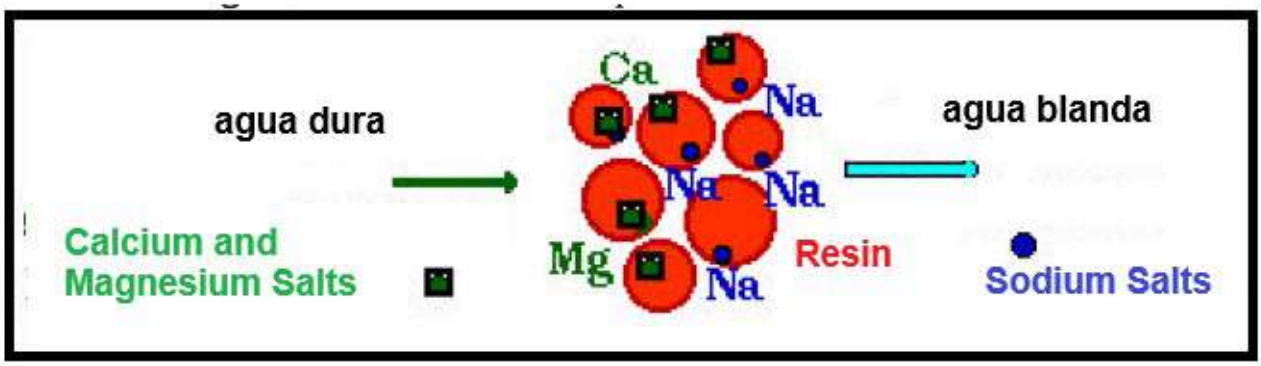
This means removing the salts that cause hardness (calcium, magnesium, iron), which can be exchanged for others that do not produce scale (such as in a water softener), or they can be completely eliminated (as in the case of distillation, precipitation, demineralization by ion exchange, reverse osmosis, etc.).

It also means removing gases (such as oxygen, CO2, etc.) using deaerators, etc.

Let's look at these topics below:

WATER SOFTENERS:

The use of ion exchangers (water softeners) in the sodium cycle is very common: it prevents sludge formation inside the boiler and reduces the amount of anti-scaling products needed (phosphates, etc.), with the drawback that it does not reduce the total dissolved salts.



The exchange material in the softener consists of small spheres (with a maximum diameter of approximately 1.2 mm) of an artificial organic material (formerly natural sands called "zeolites," which existed in some very exclusive locations), which have the property of exchanging sodium ions for calcium and magnesium ions, softening the water (other ions, such as iron, can also be exchanged).

CATION RESIN and ANION RESIN (SOURCE: indiamart.com)

The height of the resin bed must be a minimum of 600 mm (23") to prevent the formation of pathways through which hard water passes and allows the softener to "lose" hardness.

Its exchange capacity has a limit, estimated at approximately 55 grams of calcium carbonate ($CaCO_3$) per liter of resin. This means that for water with a total hardness of 100 ppm $CaCO_3$, 1 cubic meter will consume 100/55 = 1.8 liters of resin in the exchange process.

If you want to soften 10 m^3 of this water per hour, this flow rate requires a minimum of 10 x 1000/24 = 416 liters of resin in the softener bed, and will consume 1.8 x 10 = 18 liters of resin per hour.

This means that the softener will need to be regenerated every 416/18 = 23 hours. Respecting the resin volume for the maximum flow rate, regeneration times can be determined by adjusting the resin volume to suit the regeneration schedule: once a day, every two weeks, or once a week.

Once the resin is saturated with calcium and magnesium ions, it must be regenerated with sodium chloride (common salt).

The hourly capacity is very important, as a typical resin bed can handle an average of 24 liters per hour per liter of resin.

Diseño Carlos W. Thomasset

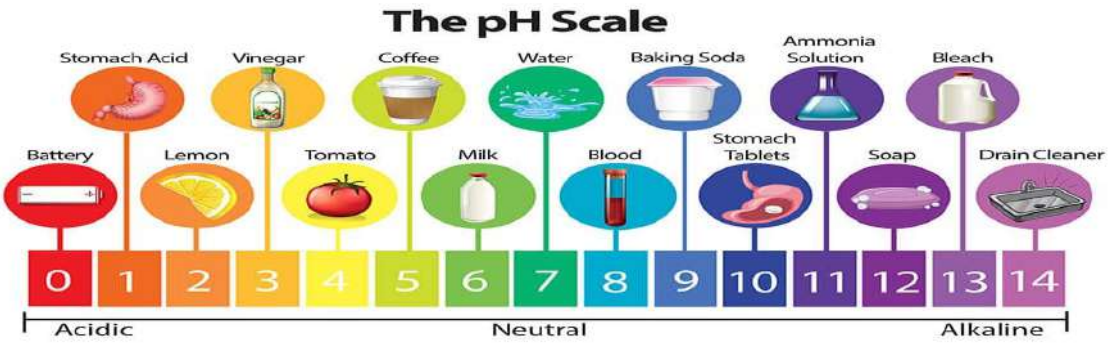
To regenerate, when brine (water with a sodium chloride or NaCl salt concentration greater than 10%) is passed through, the sodium ions displace the calcium and magnesium ions, and the sodium chloride is discharged through the drain as calcium chloride and magnesium chloride.

Therefore, when regenerating the water softener, it is important to have a specific brine concentration and to pass it through within a specific timeframe to ensure the most complete exchange possible.

Of course, this excess brine must then be removed to prevent it from flowing into the boiler (it is highly corrosive).

In other words, a water softener doesn't "remove the hardness salts," but rather exchanges the part of the salt that causes scale formation, replacing it with a non-scaling sodium ion.

However, this also has its drawbacks, as it increases the possibility of corrosion and raises the levels of "free soda," causing the pH to rise (which leads to foaming, sediment buildup, and corrosion if not limited to a maximum, generally through continuous purging and an internal chemical treatment capable of reacting with some of the sodium).



<u>Well water is generally the most problematic.</u>

One of the problems encountered when softening well water, which already contains a high level of sodium chloride (NaCl), is the self-regeneration of the water itself.

This makes complete softening difficult, and some hardness is lost due to this self-regeneration.

In these waters, it is advisable to regenerate the softener with a higher percentage of salt compared to surface water, for example, 0.200 kg of salt (NaCl) per liter of resin, instead of 0.150 kg/L.

COMMON SALT (NaCl Sodium Chloride)

Let's see how to operate a sodium cycle heat exchanger:

There are four states in which the softener can operate and three fundamental operations for its regeneration:

Normal operation

1- Backwash,

2- Brine flow (NaCl),

3- Rinse (slow flushing and fast flushing).

Normal operation:

Water normally flows from top to bottom through the softener cylinder, passing through the resin, so that calcium and magnesium ions exchange with the sodium ions present in the resin.

There is a maximum volume/flow of water that can be exchanged.

If this amount is exceeded, hardness (calcium and magnesium) will escape and will still going in the boiler feed water.

Once the system is "exhausted," meaning the water starts to become hard, it must be regenerated:

1- Backwash, 2- Brine, and 3- Rinse.

Previously, the water in the softener was tested to determine if it was soft or hard.

A special “soap” was used as a check/test; if hard water was present, it would not form soap lather (it would not saponify), while if soft water, it would immediately form lather on its surface.

If hardness had to be measured, it was proportional to the amount of soap used to form lather.

These "calibrated" soaps were specially manufactured for that purpose.

Today, more practical methods are used, such as an indicator based on Eriochrome Black T (a substance used for industrial dyeing) and a buffer (a pH regulator close to 10 for the indicator to function).

SOURCE: https://i.ytimg.com/

This indicator produces a transparent blue color in soft water and a "wine lees" color in hard water.

In this case, if hardness is to be measured, a "hardness sequestering" salt is used.

This salt is added to a sample with the indicator until the water softens. The color changes from "wine lees" to "transparent blue."

The amount of sequestering agent used (usually EDTA), depending on its concentration and the sample size, is multiplied by a factor to calculate the total hardness of the sample.

The hardness indicator for water softeners is made from Eriochrome Black T, a product widely used for dyeing, with a buffer (if used in powder form, generally ammonium chloride). A few drops of ammonia must be added to the water being analyzed to raise its pH to pH 10.

However, as a water softener indicator, it is best to use Eriochrome Black T dissolved in triethanolamine (with some buffer such as ammonium chloride).

The minimum amount of indicator should be used in each case to avoid errors in the "zero" hardness reading, since the color change of these indicators consumes some of the hardness (and they require the presence of magnesium to react; that is, in very rare waters that do not contain magnesium, a small amount of magnesium chloride must be added to the ETDA solution when preparing it to trigger the indicator reaction).

See Part 2 for the preparation of the EDTA.

1- Backwash:

The direction of water flow is reversed (from bottom to top) at a sufficient rate to remove the sludge deposited on the resin that has acted as a filter.

This water is then discharged down the drain, using a flow rate that can remove the sludge without damaging the resin.

10 to 20 minutes is sufficient (until the water is clear).

This sludge must be removed; otherwise, it allows the formation of "pathways" or "short circuits" (TRAKING) that permit the passage of hard water (loss of hardness).

It also creates a breeding ground for microorganisms that clog the resin, preventing it from functioning properly.

2- Brine or Regeneration:

Prepare the brine (10% clean, edible salt, free of iodine, fluoride, iron, etc.) in a quantity that will depend on the size of the water softener and the quality of the water being treated.

The brine is poured "slowly" (30 to 50 minutes), usually from top to bottom, discharging the effluent into the drain. Ensure that no air enters the softener; if air does, it must be removed before continuing with the brine rinse.

It is not advisable to leave the brine circulating inside the softener; this hinders resin regeneration and makes rinsing difficult.

Regeneration occurs through the displacement of the salt that was exchanged by the new salt that displaces it.

For calculating the amount of salt: 0.150 kg per liter of resin
that the softener contains, and up to 0.200 kg/L in the case of very hard water.

3-Rinse:

The rinse is to completely remove the brine remaining in the equipment.

First, perform a slow rinse (slightly stronger than the brine used for the initial rinse) for about 40 to 50 minutes.

Then, perform a quick rinse of 10 to 15 minutes with a flow rate similar to that used for backwashing (from top to bottom in both cases).

Monitor the water hardness with a hardness indicator and continue rinsing until the reading is soft.

The resins in the heat exchangers can be contaminated by various organic or inorganic elements: sludge should not be allowed to accumulate inside (it is advisable to assist the backwash with a little air when the water flow is insufficient).

Softeners exposed to these contaminants must have a pre-filter or be disinfected periodically.

The water to be softened should not contain significant amounts of sodium hypochlorite (no more than 1 ppm as total chlorine) because the resin tends to degrade.

The resins last for many years, depending on contamination and how often they are regenerated. The greatest loss occurs during backwashing, and some systems do not have a mechanism to prevent backwash loss.

During extended periods of non-use, leave the softener regenerated and flooded with water. They operate best when the water circulation is modulating, as in the case of a float valve (an on-off system is not recommended).

It is advisable to monitor the water hardness every shift (6 to 8 hours).

Today, the fastest verification method is with Eriochrome Black T-based indicators, which produce a "transparent blue" color with soft water and a "wine lees" color with hard water.

To obtain the sample, run the softener at full power for a few minutes; otherwise, there is a risk that, without water circulation, the system will produce soft water with the system "exhausted" (deceiving the operator).

Boiler softeners should be "generous" to avoid frequent regenerations (which generally result in the "loss" of hard water), and personally, I believe it is better for the operation not to be automatic.

Automatic softeners do not guarantee safe operation and can lead to errors as dangerous as introducing the "rinse" or "brine" into the boiler, incidents that have occurred causing accidents.

Automatic water softeners are generally regenerated based on a set time or the volume of water that has passed through (m^3).

Both of these can be erratic, since a boiler's energy consumption depends not only on steam production but also on condensate shortages or, in the case of m^3, variations in water hardness (such as the effect of rainfall on surface water, the mixing of water from different wells, or incomplete regeneration).

If automatic softeners are preferred, they should be monitored by a Total Hardness meter, which would trigger the regeneration cycle or bypass the hard water and sound an alarm so the boiler operator can take action.

Given all these drawbacks, manual water softeners are preferable for boilers.

However, one problem with water softeners, whether automatic or manual, is preventing "water hammer," which occurs when they use fast-acting valves (such as solenoids or large, fast-acting pneumatic valves instead of slow-acting ones).

The rapid (almost sudden) closure of the water flow after passing through the softener causes all the dynamic energy of that water to accumulate, manifesting as a pressure increase. In some cases, this pressure can rise several times the inlet pressure, causing the resin tanks to rupture (due to the repeated pressure increases and decreases that eventually fatigue and crack the material).

These water hammer effects must be avoided; the best solution is to install float-type control valves for the water softeners in the soft water tanks (which open and close slowly following the water level), or alternatively, to install pneumatic valves with delay controls for opening and closing.

We have verified that when a water softener connected to a water pressure of 4 kg/cm² is quickly closed (as with a standard solenoid or pilot-operated valve), the pressure instantly reaches 20 kg/cm². Over time, this causes cracks in the softener's tank, which is made of thick stainless steel.

Installing a relief valve is insufficient, as there is a delay in the valve's instantaneous action. It is always advisable to use slow-acting valves in soft water tanks.

1200 Lt resin softener (C.W.T: design)

WATER DEMINERALIZATION

Water demineralization is the process of removing all dissolved salts from water that no longer contains suspended elements.

Let's look at: CHEMICAL PRECIPITATION, DISTILLATION, EXCHANGE DEMINERALIZATION, and REVERSE OSMOSIS.

To control the quality of demineralized water, the electrical conductivity of salt ions in water is used (salts or inorganic substances, and some organic substances, ionize to a greater or lesser degree.

Colloidal silica and some organic elements have practically no effect on the transfer of electrical current in water because they do not ionize easily).

The electrical conductivity allowed by salts or some organic substances in water (pure water is practically a poor conductor, meaning it is almost an insulator), when a voltage is applied between two electrodes separated by a certain distance, allows for a measurement of the amount of salts in that solution.

This measurement must be corrected for the temperature of the sample, since at higher temperatures, a greater current flows, meaning lower resistance.

This standard temperature is generally 25°C (77°F), and it can be considered that conduction increases by 2.2% for every 1°C (33.8°F) increase in temperature.

Therefore, this measurement is made either by conductivity (current flow, measured in Siemens per centimeter or micro-Siemens per cm, or µS/cm, the most commonly used unit (micro = µ = 0.000001 S, given the extremely small values, the Siemens being the unit of conduction equivalent to a circuit with a resistance of 1 Ohm when a voltage of 1 volt is applied)),

Or equivalently, by inverse resistance (resistance is measured in Ohms, the inverse in Mho, a way of expressing conductivity), which is expressed in Mho/cm or microMho/cm, or µMho/cm. (micro or µ means one millionth, or 0.000001 or 10^{-6}, given how small the conductivity can be in almost pure water between two 1 cm^2 plates at a distance of 1 cm, when the voltage is 1 volt).

But Siemens was chosen instead of Mho (both are equivalent).

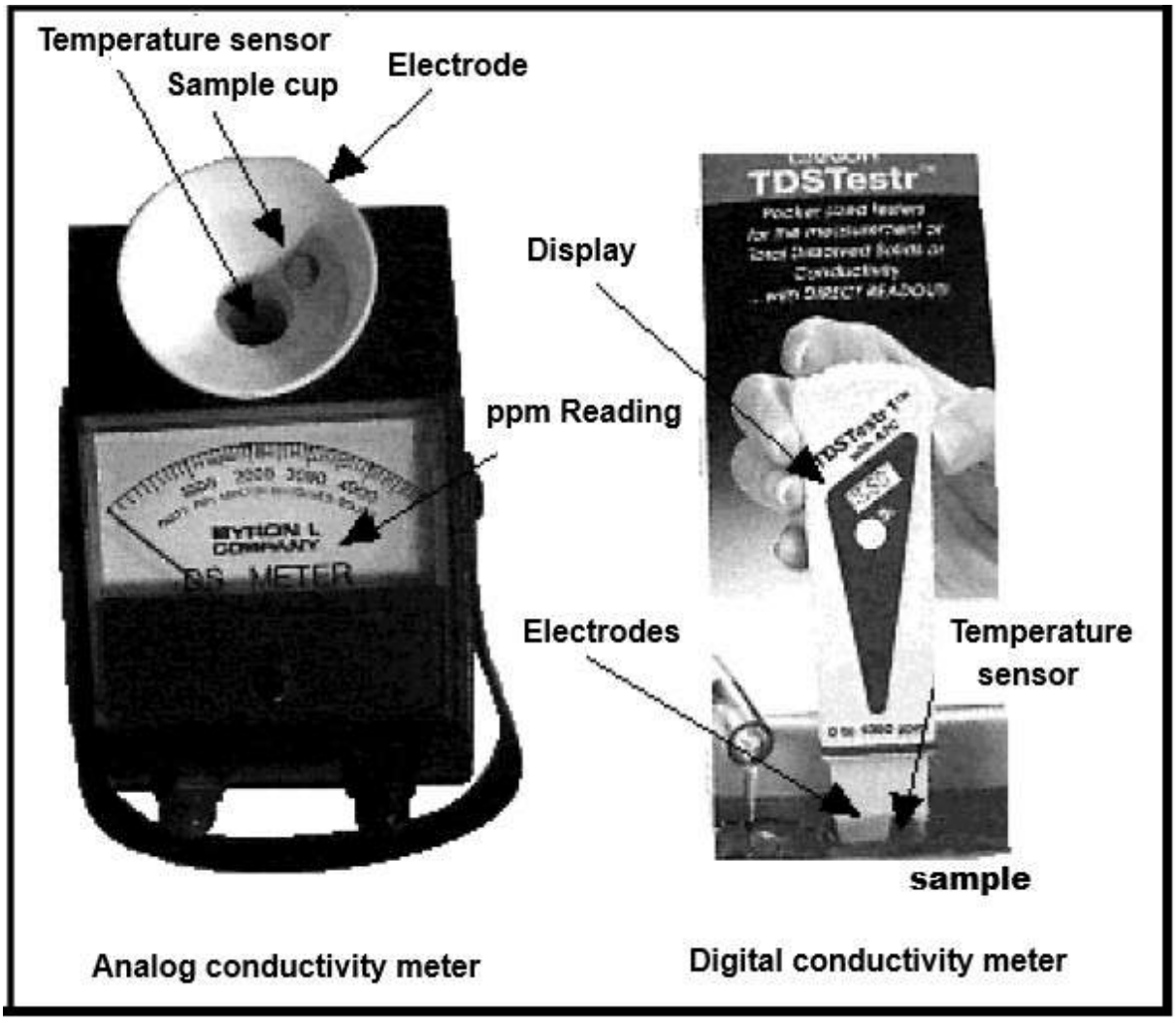
Other values related to conductivity can be expressed in millisiemens (mS, meaning one-thousandth of a Siemens, since 1 mS/cm = 1,000 µS/cm or milliMho: mMho).

Or it can be expressed as resistivity or resistance and is generally expressed as megaohm-cm (MΩ), the inverse of conductivity (mega, meaning one million times, or times 1,000,000 or 10^6), or it can be expressed in kiloohm-K - equal to 1,000 times the ohm.

The purest water achieved was established at 4.2×10^{-6} Siemens per meter at 20°C (or 0.042 µS/cm), or expressed in ohms, at 23.8 MΩ·cm.

In practice, these values are very difficult to achieve.

Parts per million (ppm), in which the salt content is expressed, refers to one unit of weight dissolved in one million (1,000,000) total units of solution, which can also be expressed in parts per thousand (ppt).



In general, we can say that the approximate values for different types of water will be (at 25°C, as is generally the case):

Super pure .....approx. 0.055 µS/cm
Distilled.....approx. 1 µS/cm
Wells.....+ 500 µS/cm
Sea water.....approx. 58 mS/cm

Surface water salinity varies in Uruguay, generally ranging from 70 µS/cm (approximately 50 ppm of salts in the Litoral region) to over 300 µS/cm (approximately 200 ppm in the Santa Lucía River during dry periods).

In wells, salinity increases, particularly in the eastern departments near the ocean, especially when the wells are deep.

The instruments used for this control generally have their readings automatically corrected for the sample temperature. They also operate with high-frequency alternating current to prevent the measuring electrodes from becoming "polarized" (i.e., covered with a gas from the decomposition caused by the current, which would alter the reading, since alternating current depolarizes in each half-cycle).

However, be careful; remember that silica and other organic elements may be present and the conductivity meter will not detect them.

Instruments can have analog readings (instruments with needles) or digital readings (instruments with screens, like calculators).

Both types of instruments must be calibrated periodically (with a sodium chloride solution specially prepared for this purpose; in boiler water, the calibration solution can be 4,500 µS/cm, equivalent to 3,000 ppm, not corresponding to 3 g/L of NaCl and water solution, but to a lower value, 2,350 mg/L of sodium chloride).

Keep their electrodes clean (using alcohol, preferably isopropyl, or sometimes a dilute acid solution—for example, 5-10% hydrochloric acid—rinsing thoroughly after a few minutes).

After cleaning the electrodes, calibrate them with the solution, allowing sufficient time to compensate for temperature variations (today, virtually all instruments have automatic temperature compensation at 25°C (77°F).

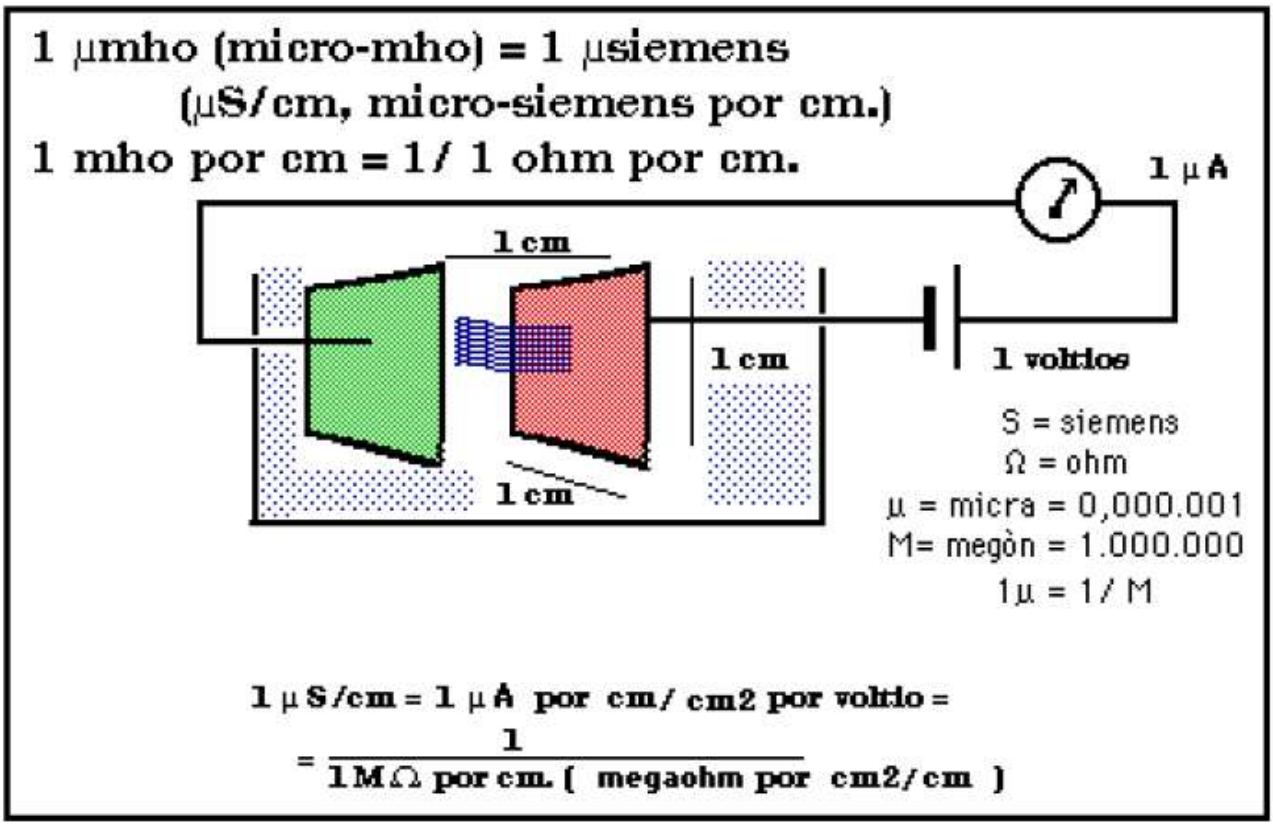
NOTE: Like pH meters, conductivity meters, if they are low-cost instruments (costing only a few dollars), will quickly lose their calibration and give false readings (inaccurate, unreal values).

Conductivity meters for monitoring demineralized water (fixed installations) generally have an automatic function that "aborts" (and triggers an alarm) if the water's conductivity exceeds the regulated level.

It's important to analyze for silica, as it can be present even with low conductivity readings.

The desired values depend on the demineralization system. Generally, we can say that 1.5 µS/cm is equivalent to 1 ppm, or 0.66 ppm per µS/cm (in boiler and natural water), and less than 0.6 ppm per µS/cm (in demineralized water or condensate).

Let's visualize the above relationships:


1 µmho (micro-mho) = 1 µsiemens
(µS/cm, micro-siemens por cm.)
1 mho por cm = 1/ 1 ohm por cm.
1 µA
1 cm
1 cm
1 cm
1 voltios
S = siemens
Ω = ohm
µ = micra = 0,000.001
M= megòn = 1.000.000
1µ = 1/ M
1 µS/cm = 1 µA por cm/ cm2 por voltio =
= 1 / 1MΩ por cm. (megaohm por cm2/cm)

When measuring TDS (Total Dissolved Salts) in boiler water using a conductivity meter, if the sample isn't adjusted to a neutral pH, we're actually measuring conductivity (the higher the pH, the higher the conductivity, with the same total dissolved salts; what changes is the type of salts).

To adjust the reading to a neutral pH, non-ionizing organic acids (such as gallic acid, 3,4,5-trihydroxybenzoic acid) are used.

But in reality, what most affects boiler performance is not the quantity of dissolved salts, but the type of salts that alter the water's surface activity, thereby affecting internal circulation (potentially causing foaming, which promotes carryover, or even cutting off internal circulation, leading to insufficient local cooling that can even cause a fire-tube boiler to collapse).

In reality, when we don't adjust the pH, it's the conductivity value that we must respect, because it's the one that affects us most (and by setting a limit in ppm, corresponding to a specific maximum conductivity value, we are protecting against internal circulation problems; that is, measuring without adjusting the pH, or otherwise speaking in terms of conductivity and not ppm).

There is a tendency to be misled by this reasoning, since previously dissolved solids were measured by "evaporation" (after filtration), or by a "weighing" densimeter (with a "density" salinometer corrected for sample temperature).

Both systems do not take into account the conductivity of the water, which could be close to the desired TDS value, but in a risk zone for the internal circulation of the boiler.

Always remembering that this conductivity method does not measure the presence of silica, which generally does not affect the conductivity of the water

But can be a dangerously high threshold, especially when generating superheated steam for steam turbines, which are seriously affected by silica-laden water carryover.

CHEMICAL PRECIPITATION

Initially, in early steam boilers (along with distillation), salts were extracted by adding chemicals (lime, soda, phosphates, magnesium, etc.) to precipitate the dissolved salts, followed by filtration to remove any remaining suspended elements.

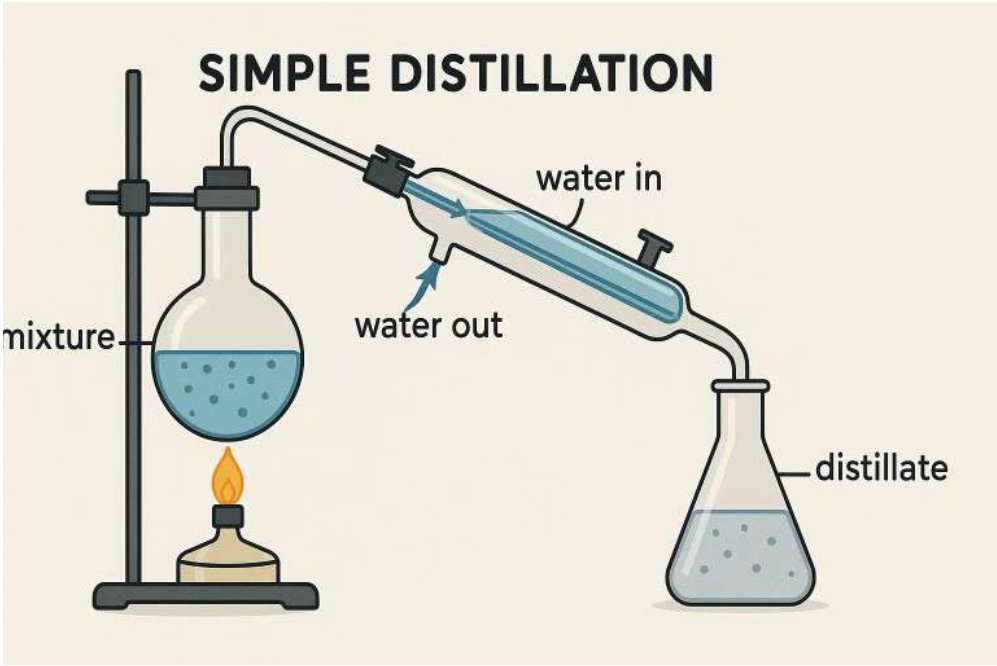
This involved veritable water treatment plants, with dosing, mixing, sometimes heating, precipitation, filtration, etc. The resulting water has a lower salt content, but not enough to be considered "pure."

It is still a valid method when used in combination with other demineralization processes to obtain "pure" water (with or almost no salts), since in water with high salt content or salts that precipitate easily, the other processes may not work correctly.

Let's look at the processes that "fine-tune" water purification (distillation, demineralization, reverse osmosis).

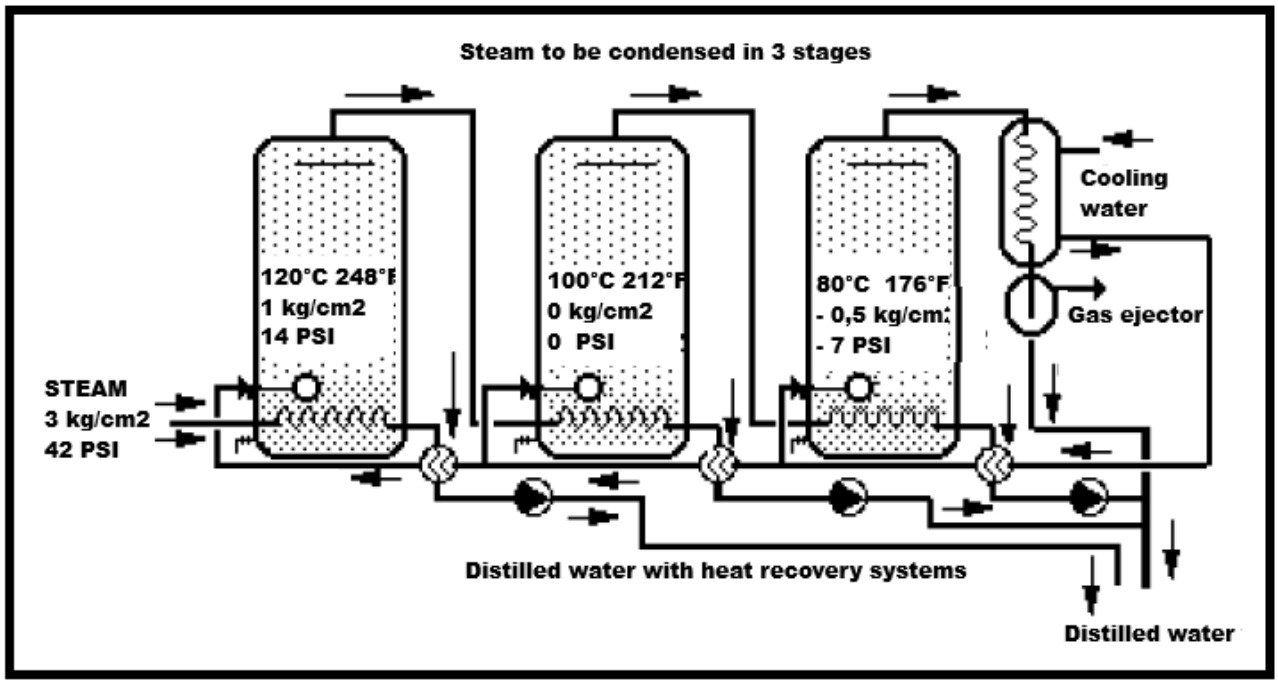
DISTILLATION

In the past, near-complete demineralization of water was achieved through evaporation and condensation (stilling distillers). By repeating the process, a fairly acceptable level of water purity was obtained.



This distillation process consumes energy (steam, direct heating, electricity, etc.). To improve efficiency, it can be carried out in several stages, taking advantage of the "latent" heat of each stage and the sensible heat of the "distilled" water. This type of still can be a multi-stage distiller (in series) or a single-stage distiller (in parallel).

Using the distillation vapors in subsequent stages reduces energy consumption, as the process is repeated at a lower pressure, with the final stages occurring below atmospheric pressure. (Alternatively, mechanical "thermo-compression" is used, compressing the distillate vapor to capture the "latent heat" of the steam, which is then reused to heat the water to be evaporated.)



Water purity is measured by its conductivity.

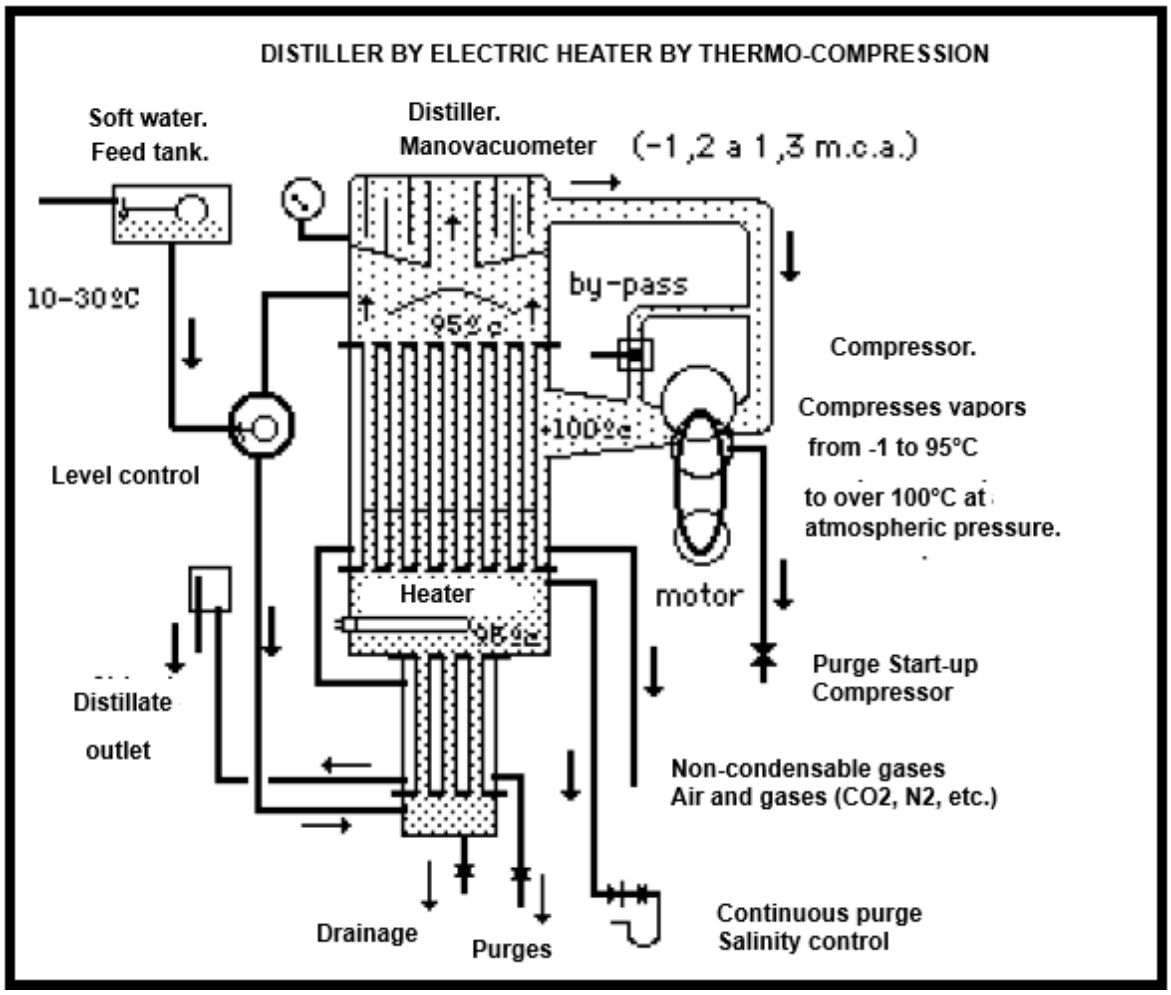
Although silica—SiO2—is not detected because it is non-ionizable, this can be a very serious problem, given that silica produces very hard, insulating scale and, in medium- and high-pressure boilers that operate with turbines, can scale the turbine blades (reducing efficiency and causing imbalances that result in vibrations that can destroy the turbine).

One of the problems with distillers is the scaling that occurs within the distiller itself; another is the management required to prevent the carryover of salts from the distilled water into the steam.

The resulting water purity is quite good; repeating the process achieves a purity almost as good as that obtained through demineralization by exchange.

One of the advantages of distillation is that, because it is carried out at a specific temperature, the distilled water is disinfected, generally resulting in water free of pyrogens (contaminating microorganisms), provided the distillation is performed at a sufficiently high temperature (this is not the case when distilling below 100°C (212°F), i.e., under vacuum—below atmospheric pressure—in an attempt to increase thermal efficiency).

One of the reasons for carryover in distillers can be: excess salts due to insufficient continuous purging of the water being distilled, water contamination with elements that cause foaming, scale buildup on surfaces, excessive distillation frequency, a very high water level, problems with the droplet separator baffles, the distiller operating at pressures different from its design specifications, etc.



Some chemical products can be used to prevent scale buildup in the distiller, but the best solution is to soften the water by ion exchange (sodium-cycle resin softener), ensuring continuous purging of the distiller, due to the excess alkalinity, which can form foams that cause carryover.

From the previous figure, a still using "mechanical thermo-compression," let's look at the basic operation:

The vapor produced in the heat exchanger-evaporator, which is heated by thermo-compression (or initially by electric resistance heaters), is discharged into a separation chamber. In this chamber, water droplets are removed through labyrinths and filters, and the vapor is drawn in by the compressor's suction at approximately 93-95°C (-1.2 to -1.3 m.w.c.). It is then compressed by the compressor, increasing its pressure (0 m.w.c.) and therefore its temperature (+100°C).

Mechanical work from the electric motor is added, which is transformed into temperature and pressure. The discharge of these hotter vapors collides with the tubes of the heat exchanger-evaporator containing the saline water to be evaporated. The vapor from the compressor condenses, and the saline water evaporates.

The heat of vaporization is almost exactly the same as the heat of condensation, approximately 600 kcal/kg. The temperature difference allows heat transfer from the condensate to the saline water, since there is a difference caused by the different pressure and temperature conditions on each side of the process.

This phenomenon allows distillation to occur in a nearly closed cycle using very little energy, only compensating for losses (with electrical resistance).

The condensed water releases its non-condensable gases into the atmosphere (CO_2, O_2, N_2, NH_3, etc.), and the water continues by gravity to the heat exchanger with cold feed water before exiting.

1200 liters SOFTENER C.W.T. design

CHAPTER 17: BOILER WATER PREPARATION Part 2

DEMINERALIZATION BY ION EXCHANGE

Demineralization by ion exchange consists of using "resins" (similar in appearance to those used in water softeners), which are small spheres (the most common form) that have the property of exchanging ions (salts are formed by an acidic radical and an alkali radical; if they are ionizable, when dissolved in water, they can form ions of their radicals, some positive and others negative).

Resins can be classified according to their exchange mechanism:
those that exchange acid radicals (cationic resins, similar to those used in water softeners) or alkali radicals (anionic resins).

Once regenerated, the acidic (cationic) resins react with acids (containing H+, hydrogen ions) and the alkali (anionic) resins react with sodium hydroxide (NaOH), which contains hydroxide ions (OH-).

Resins that exchange alkali radicals, or cationic resins (Ca++, Mg++, Na+, K+, etc.), release an acid radical into the water by donating an H+ ion.

This acid radical is then exchanged by the alkaline or anionic resin for an OH- ion.

In short, the salts will be exchanged, forming H_2O (the union of H^+ and OH^-), that is, water.

Generally, the water must be pre-treated to remove all organic and suspended contaminants, and its chlorine content must be reduced to a very low level (less than 1 ppm).

It is usually exchanged first with the cationic resin (this eliminates alkaline radicals that can precipitate and hinder the exchange), and then the acidic radicals are exchanged in the anionic resin.

To achieve high water purity, this process must be repeated several times, or alternatively, a mixed bed can be used (a mixture of cationic and anionic resins, so that the exchange occurs alternately within the column itself on repeated occasions).

This topic offers many alternatives. But let's talk about the problems that can arise.

Anionic resin, which exchanges acidic radicals (and also exchanges silica or SiO2 as a slightly acidic radical), is highly susceptible to fouling (contamination with organic elements that reduce the resin's exchange capacity).

When anionic resin becomes contaminated, the reduced exchange capacity allows acidic radicals to pass through (resulting in a low pH in the water).

This is detected by the conductivity meter (as we saw in Part 1, this device monitors the conductivity of water, which is produced by ions or electrical charges. Since pure water is practically an insulator, this can detect the passage of salts or radicals in the treated water).

Therefore, the system is monitored and regenerated or disinfected upon detecting conductivity.

However, the problem can be more serious if silica (SiO2) is a concern for the plant, since the conductivity meter doesn't detect the presence of silica because it is almost non-ionizable (it doesn't significantly increase the conductivity of demineralized water).

If silica removal is truly desired, the anionic resin must be regenerated with the soda solution at a specific temperature—generally no higher than 50°C (122°F)—to avoid affecting the stability of the anionic resin, which is less heat-tolerant than cationic resin, some of which can withstand up to 140°C (284°F). If this temperature isn't maintained, the resin won't be properly regenerated to remove the silica.

Anionic resin generally has a volume 20% greater than cationic resin for the same exchange capacity, given its lower exchange capacity.

Although there are many types of resins, anionic resin is generally less dense than cationic resin. This allows for separation in mixed beds for regeneration (this is done with a countercurrent water flow), and they are remixed after regeneration and rinsing (they are premixed with air bubbles in the column partially filled with water).

Anionic resins are regenerated with dilute acids, with hydrochloric acid being one of the best (because there is no precipitation, but one of its problems is that if the column is made of stainless steel, it is attacked by the chloride ion).

When using other acids, such as sulfuric acid, it must be very well diluted and in low percentages, since it precipitates if it combines with some of the cations in the regeneration process if it is present at a certain concentration.

Furthermore, it must be handled with great care; it is a very dangerous acid to handle, both because of the mistake of introducing water into the acid: it almost causes an explosion due to the development of intense heat, and because if any part of the human body comes into contact with the acid, it suffers immediate ulceration that puts the person's health at risk.

Generally, sulfuric acid is cheaper than hydrochloric acid, which is why it is used in some plants (despite the risks).

If the water needs to be chlorinated for disinfection before demineralization or softening, it's advisable to remove the residual chlorine as it enters the heat exchange system.

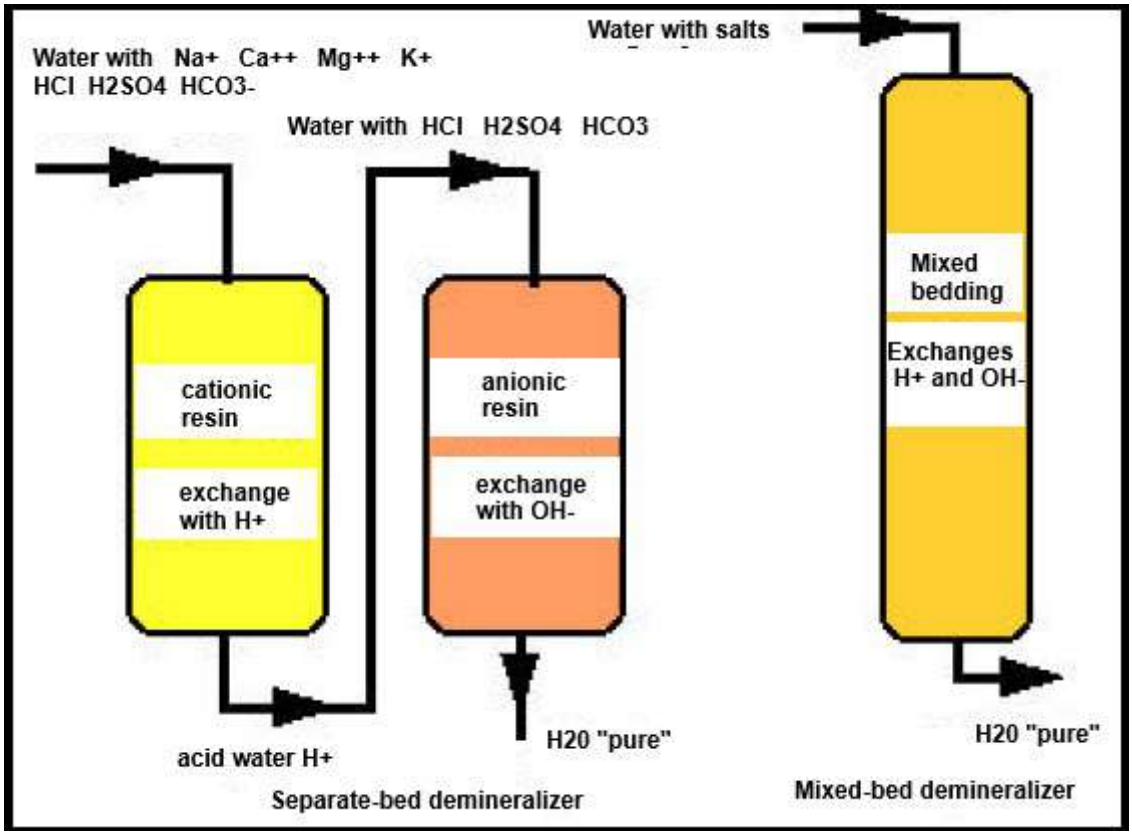
For this purpose, an activated carbon filter is installed. Activated carbon comes from various sources, but all are generally composed of carbon and have high porosity, providing a large surface area for absorbing elements such as chlorine, other gases, or organic materials.

Although there are carbons designed for other absorption functions, such as the removal of odors, tastes, colors, or the organic elements that produce them, etc.

These carbons are replaced or partially regenerated with a counter-current steam flow and vented to the atmosphere (although for greater recovery, they should be treated at high temperatures, almost to the point of calcination).

Among the various resin combinations, to achieve better exchange, a carbon dioxide (CO_2) removal tower can also be used between the cationic and anionic resins. CO_2 is produced when there is high alkalinity in the water being treated, generally well water, which is composed of acidic carbon dioxide radicals from bicarbonates.

Let's look at some simple example diagrams.



REVERSE OSMOSIS

To extract the salts contained in water (both soluble salts and those elements that are not completely soluble, such as organic compounds), there are currently methods that take advantage of the osmosis effect by applying a reverse effect, in order to obtain almost pure or demineralized water.

The effect called osmosis occurs when, in a container divided into two parts by a semipermeable organic membrane, one section contains water with salts and the other pure water, both at the same level.

We will see that the pure water tends to pass through the semipermeable membrane, causing the side with the water containing salts to rise to a certain height. This difference in height is the osmotic pressure.

But if we make the side containing the salts more pressure than the osmotic pressure (or height), we will be able to draw pure water from the salt solution into the pure water section.

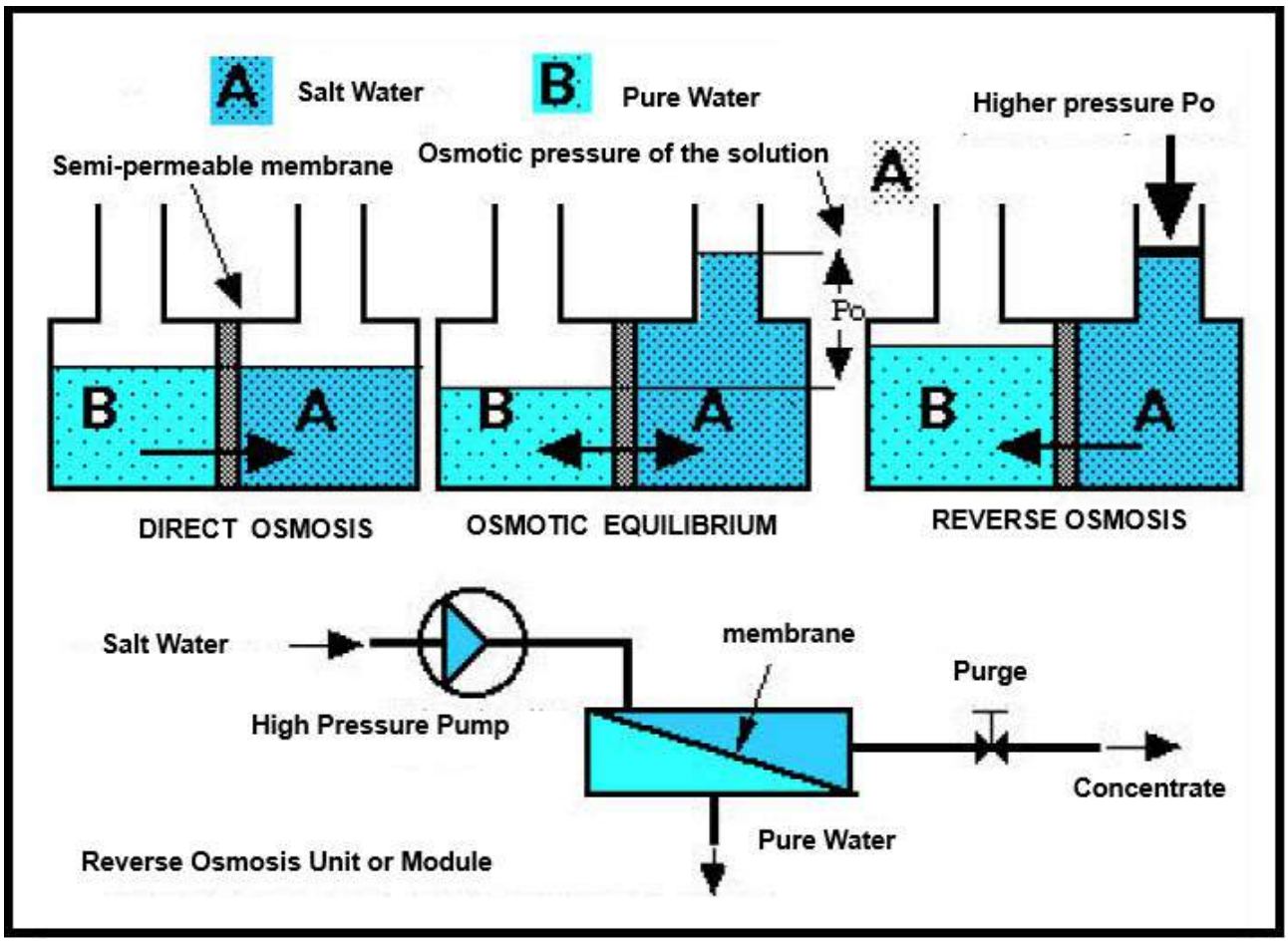
If we achieve this effect with large surface area membranes (made of cellulose acetate or polyamides, suitable for this purpose; the former have a high transfer capacity but are very sensitive), we can pump water with salts and extract a portion of that water with a lower salt concentration.

There will always be a continuous purge to maintain a limit on the salt concentration, since a higher salt concentration requires more pressure and also increases the loss of salts introduced with the clean water.

If we perform this effect in several stages, we will ensure that the "pure" water is progressively purer in each "effect" or reverse osmosis module.

The pump pressure is generally in the range of 20 k/cm² (284 PSI) to 80 k/cm² (1138 PSI).

The membranes have special shapes (spiral, tubular) and require periodic cleaning to maintain them in good condition. Their lifespan depends on the type of material and the local conditions of each system.



In some cases, the water to be treated must be prepared (due to an unsuitable pH, excessive hardness, suspended solids, disinfection, etc., or the use of antiscalant polymers in continuous dosing).

These systems have a promising future, as they can replace ion exchange, which generates significant pollution during resin regeneration (acid, soda, etc.).

These systems have proven highly useful not only in industrial applications but also in seawater purification, both on ships and in some desert regions.

The ratio between the flow rate of purified water and the feed flow rate is called conversion (expressed as a percentage).

The ions that tend to pass through most readily are those with the lowest atomic weight. Generally, sodium chloride losses are the most common, requiring more reverse osmosis passes (through membranes) to reduce these losses.

This necessitates the use of mixed resin beds at the end of the reverse osmosis chain when ultrapure water is required. This ensures sufficient water purity for use in high-pressure boilers, as well as other applications (cleaning electronic circuits, etc.).

FEEDWATER DEAERATION

Water, regardless of its source, contains dissolved gases (even demineralized water, whether from ion exchange or reverse osmosis, generally does not remove these gases, except for distilled water that exits at a temperature close to 100°C (212°F), which contains almost no gases).

Among these gases is oxygen (which makes up 21% of the atmosphere by volume, a highly corrosive element for boiler and steam systems), and its concentration must be minimized.

There are several ways to reduce it to a minimum.

One method is sequestration with a chemical (for example, sodium sulfite, hydrazine—the latter being carcinogenic and therefore not suitable for every plant, as there are other substances that can be used, though not as commonly as sulfite).

The problem with sequestration using chemicals is their cost, and in the case of sulfite, the increased amount of salts to be purged (which is why the aim should be to remove as much oxygen as possible through thermal or mechanical means, in order to use the minimum amount of sulfite).

To reduce the use of these chemical elements, we have two methods that can be used together or separately:

1- Heating the feedwater to its maximum temperature (as close as possible to 100°C (212°F) to eliminate all gases, since at atmospheric pressure, most of the oxygen will be expelled from the water.

This is seen in everyday life when you open a "hot soda"—it loses its fizz—and when you open a cold one, the carbon dioxide remains almost entirely in the liquid), or heating above 100°C (212°F) with steam purging (this causes the oxygen to be released from the water and expelled from the feed tank; this is called a deaerator).

2- The other method is creating a vacuum or decompression (which, if aided by heat, will practically eliminate the gases contained in the water).

There is a way to remove oxygen using exchange resins, a method that is not very widespread (these resins are regenerated using chemicals).

To see the influence of temperature on the oxygen content of water under atmospheric pressure, refer to the following table:

TABLE OF OXYGEN CONTENT IN WATER ACCORDING TO TEMPERATURE
(at atmospheric pressure, i.e., tank vented to the atmosphere).

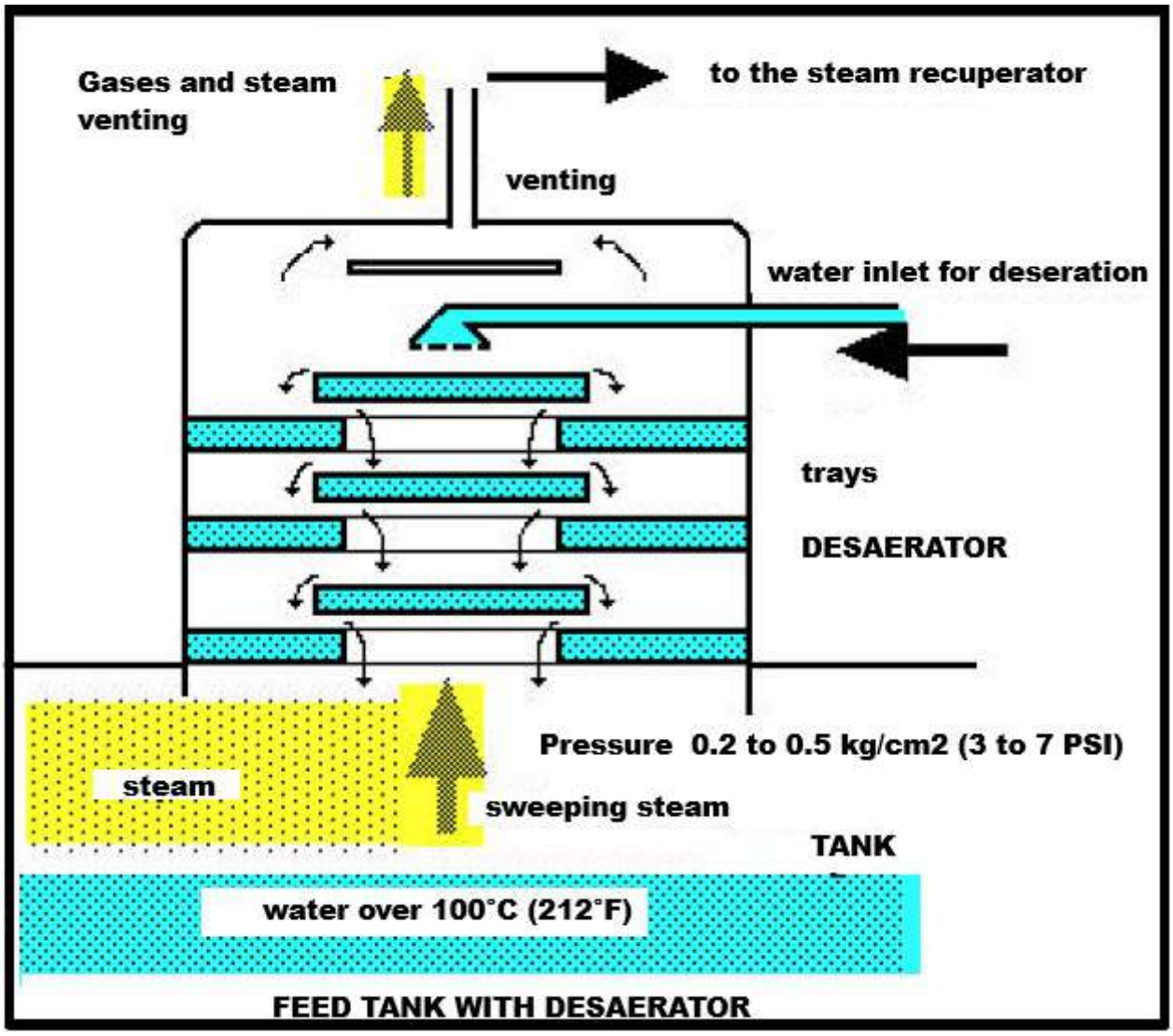
TEMPERATURE IN °C	OXYGEN CONTENT mg/kg
10ºC (50°F)	11,25
20ºC (68°F)	9,09
30ºC (86°F)	7,49
40ºC (104°F)	6,41
50ºC (122°F)	5,50
60ºC (140°F)	4,69
70ºC (158°F)	3,81
80ºC (176°F)	2,81
90ºC (194°F)	1,59
95ºC (203°F)	0,86
99ºC (210°F)	0,18

The feedwater tanks are generally open to the atmosphere (vents) and lack any gas extraction systems. In these cases, the water can be heated by steam injection, a coil, or condensate recovery, to as close to 100°C (212°F) as possible.

To achieve this, the tank must be at least 5 meters above the feedwater pump suction; otherwise, cavitation will occur (steam will form in the pump's volute, causing it to fail and requiring the feedwater to be cooled).

Remaining oxygen will be removed with chemicals (maintaining a residual level in the boiler water).

Feed tanks equipped with "deaerators" operate on the principle of heating the feed tank's makeup water in a counterflow, thus maintaining gas venting and using a small amount of "purge" steam (this steam can be recovered in a cooler or heat exchanger with the same cold makeup water, recovering both the condensate and the heat).



To keep the feed tank isolated from the atmosphere and at a temperature above 100°C (212°F), the tank must be slightly pressurized.

The steam injected countercurrently maintains a small internal pressure in the tank (the tank must have all the necessary safety features to ensure this small pressure does not exceed its value, as this could cause an accident due to tank explosion; generally, good pressure regulators are installed, in addition to relief valves and/or water-sealed columns).

These deaeration tanks must be inspected frequently, as they can develop fatigue cracks, posing a safety risk to plant personnel.

Any remaining oxygen, which is very low in this case, must also be chemically removed, leaving a residual value of the sequestering agent in the boiler water.

Feeding the boiler with cold water is bad for several reasons, from excessive consumption of oxygen scavenger to the boiler's lack of response to changes in operating conditions, apart from internal thermal shocks, which can lead to structural problems.

C.W.T. In one of the long trips in the Tacoma ship to Panama or Oribe oil tanker ship to Arab
Big boilers and steam turbines to deal with

CHAPTER 18: BOILER WATER CONTROL Part 1

This chapter will cover boiler water control (its chemical treatment), including basic water analysis.

It is advisable to use a color code to distinguish the different reagents we will use, which reduces the risk of human error. In addition, the solutions should be labeled.

All analyses are based on an indicator that shows the color change of the solution being measured (i.e., the point at which a substance (titrant) must be added to measure the parameter.

The amount of titrant consumed to reach this color change is called titration).

We can use plastic syringes to measure the amount of titrant solution, adding it drop by drop while swirling the sample (in an Erlenmeyer flask) to a quantity appropriate for the expected concentration.

When we say N/10 (normality 10) of a solution, it refers to the molecular concentration of a substance in the solution.

For example, if we say "Normal Solution" of sulfuric acid, it means that the weight of the sulfuric acid molecule in grams is dissolved in 1 liter of distilled water.

Always add acids to water, not the other way around, as a hot reaction can occur that may splash and cause burns (a chemical attack on the skin; the most dangerous risks are not protecting the eyes and inhaling the released gases).

Therefore, when we say N/10 or "normal tenth," it means one-tenth of the molecular weight in grams dissolved in distilled water to 1 liter.

COLOR CODE:

1-Red.....Phenolphthalein Alkalinity

2-Gray....Total Alkalinity

3-Black...Chlorides

4-Blue.....Total Hardness

5-Yellow.....Phosphates

6-Green.....Sulfites

7-pH

8-Salinometer.

The product names for each code are found in the detailed analysis report. This color coding is personal in my case (C.W.T.).

The factor by which the titrant consumption must be multiplied to determine the amount of the element being measured depends on the sample size and the normality of the titrant.

For example, the factors listed below are for
Sulfuric Acid N/10 (Red and Gray alkalis),
ETDA N/50 Total Hardness Sequestrant (Blue),
and Silver Nitrate N/10 for chlorides (Black):

TABLE OF FACTORS BY SAMPLE VOLUME:

Sample Quantity	RED	GRAY	BLUE	BLACK
100 ml	ml.x50	ml.x50	ml.x10	ml.x35.5
50 ml	ml.x100	ml.x100	ml.x20	ml.x71
25 ml	ml.x200	ml.x200	ml.x40	ml.x142
Results:	**ppm CaCO3**	**ppm CaCO3**	**ppm CaCO3**	**ppm Cl-**

1_RED....PHENOLPHTHALEIN ALKALINITY (color change approximately at pH 8.3-8.4):

Take the sample, let it cool, and measure (100 ml, 50 ml, or 25 ml).

Add a few drops of phenolphthalein (red dropper). If there is no red color change, the analysis is complete, and the result will be zero.

If there is a red color change, using the (red) syringe, draw 5 ml of N/10 sulfuric acid from the (red) bottle and add it drop by drop (while continuously stirring) until the red color disappears and the water returns to its initial color.

The reading in ml of acid used, multiplied by the corresponding FACTOR, gives the Phenolphthalein Alkalinity in ppm as CaCO3.

Do not discard the sample and continue using the (red) syringe with the remaining acid.

2_GRAY....TOTAL ALKALINITY (color change at pH 4.3):

Continuing with the previous sample, add a few drops of Methyl Orange (gray dropper).

The agitated sample will turn a pale yellow color.

If it turns pink (salmon red), the analysis is complete, and the reading will be the same as the Phenolphthalein Alkalinity.

In the first case, a yellow color, continue adding the acid from the syringe (red) or refill it if all the acid has been used, drop by drop, while continuously agitating until the pink color appears.

The reading of the ml used will be from the beginning of the Phenolphthalein Alkalinity measurement.

Multiplying the ml reading by the corresponding FACTOR will give the Total Alkalinity result expressed in ppm as CaCO3.

Do not discard the sample; continue with Chlorides.

The hydroxide alkalinity ("free soda") is calculated by multiplying the phenolphthalein alkalinity by 2 and subtracting the total alkalinity (= Hydroxide Alkalinity).

This allows you to see the amount of "free soda" in the boiler water.

At low pressure (up to 10 kg/cm², 142 PSI), it is advisable that the "free soda" be less than 450 ppm as $CaCO_3$ (Sodium Carbonate), since at higher values, foaming occurs (which causes boiler water carryover in the steam and also increases the possibility of "caustic embrittlement" in areas of high vaporization).

As boilers operate at higher pressures, the "free soda" content must be reduced until it reaches a negative value (starting at 40 Kg/cm2), lowering it to levels where there is a lack of free soda so that the pH is below the Trisodium Phosphate curve (to reduce the possibility of localized soda attack on high vaporization surfaces).

3_BLACK.....CHLORIDES (Mhor method):

With the previous sample, add a few drops of Potassium Chromate until the sample turns yellow (black dropper).

Using the syringe (black), take N/10 Silver Nitrate (black bottle) and add it drop by drop (while continuously stirring) until a permanent brick-red color appears.

The reading of the ml of N/10 Silver Nitrate used multiplied by the corresponding FACTOR gives the result in ppm as Chloride ion (Cl–).

If alkalinity has not been determined for the sample, add a few drops of Phenolphthalein (red dropper) and then add N/10 Sulfuric Acid until the red color disappears.

If the sample contains sulfites (more than 60 ppm SO3–), to avoid interference, it should be converted to sulfates.

To do this, add a few drops of Hydrogen Peroxide (oxygenated water) to a new sample or leave the sample in contact with the atmosphere for several hours.

4_BLUE...TOTAL HARDNESS:

Take a fresh sample, add 10 to 20 drops of ammonia solution (blue dropper), shake, and add a pinch of hardness indicator (blue container, black powder based on Eriochrome Black T and a buffer).
Shake.

If it turns a clear blue color, there is no hardness. If the solution turns a wine-colored hue, it indicates hardness, which we will measure:

- Using the syringe (blue), take a small amount of EDTA from the blue bottle (EDTA is a hardness sequestrant calibrated to a value equivalent to N/50; EDTA is the abbreviation for ethylenediaminetetraacetic acid, plus a pinch of magnesium hydroxide so that it can change color in water that does not contain magnesium, since it is the presence of magnesium that allows it to change color at the end of the analysis) and add it drop by drop slowly (with continuous stirring) until a clear blue color appears.

The reading in ml of EDTA used multiplied by the corresponding FACTOR gives the TOTAL HARDNESS in ppm as CaCO3.

In cases of cloudy boiler water (with probable iron interference) or very high alkalinity, it is advisable to dilute the sample in 5 or 10 dilutions, then multiply the result by the number of dilutions.

The water used for dilutions must be deionized or distilled (test for hardness beforehand). Analysis is not necessary for boiler water with excess phosphates.

5_YELLOW...PHOSPHATES using a Molybdate and Metavanadate-based indicator:

Using a funnel with filter paper (if the water is cloudy), fill it with the water to be analyzed.

Place the funnel's spout into the 10 ml clear plastic tube (fill it once for rinsing and discard the excess). Refill the tube to the upper (10 ml) or lower (5 ml) mark.

Add 8 drops of indicator (yellow dropper) or 4 drops if using the lower mark.

Cap the tube, shake, and let it stand for 5 minutes. Compare the resulting yellow color.

This will be the result in ppm, read on the comparator as ppm of PO4-3 (phosphate).

The reagent used can be based on **Ammonium Molybdate and Metavanadate, sulfuric acid, and distilled water, producing a yellow color reaction with phosphate** (which can be compared visually or with a comparator) colorimeter.

Its advantage is that it has little interference (especially with silica).

6. GREEN.....SULFITES: Using dipsticks (imported: Merck® or another brand) that will measure semi-quantitatively.

Use a sample of non-aerated water. Immerse the dipstick (indicator part) for a few seconds (5 to 10 seconds), let it drain for a few seconds, and after 30 seconds (no longer), compare with the color scale.

The reading will be ppm of SO3-2

7. pH: Using pH 0-14 dipsticks (imported, such as Merck®).

In a clean container rinsed with the same water, place a cold sample of non-aerated boiler water (10 to 50 ml).

Immerse the pH indicator dipstick (it must be capable of indicating between pH 8 and 13) for a few seconds (5 to 10 seconds) and then immediately compare with the colors on the comparator.

8-TOTAL DISSOLVED SALTS (T.S.D.) Using conductivity meters for boiler water, in µS/cm or ppm

Remember that boiler water does not respond to a conductivity equivalent to a standard laboratory solution, but rather to waters with varying salt content.

This is true when calibrated for ppm (parts per million), the most commonly used standard solution being that 2.35 grams of sodium chloride per liter is

equivalent to 3,000 ppm (3,000 ppm can be said to be equivalent to 4,500 µS/cm).

Generally, the temperature compensation of these meters is automatic at 25ºC (77°F); otherwise, it will give an erroneous value if not corrected, since the reading increases as the sample temperature rises.

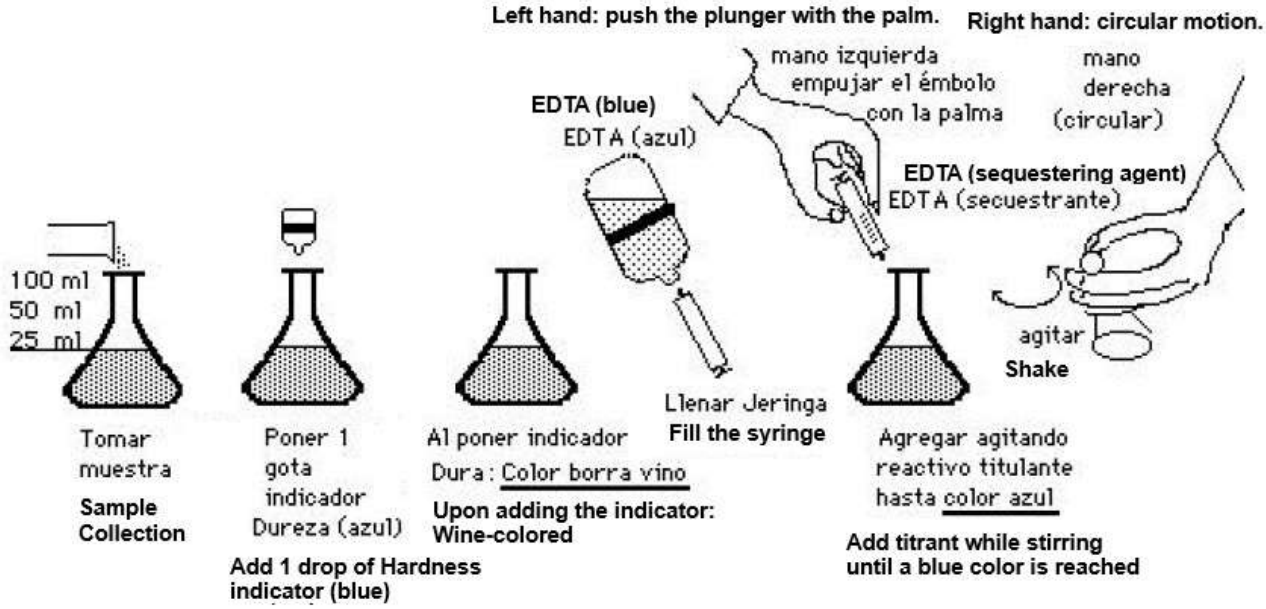
Previously, manual correction was performed by measuring the sample temperature and subtracting or adding, depending on the temperature, to the value given by the conductivity meter (manual correction).

In the case of gravity meters, temperature correction is also necessary, since the density of water varies with its temperature: Cool the sample in the same way as in the previous analyses.

Follow the instructions for the meter being used, whether it is a conductivity or gravity meter.

TOTAL HARDNESS METER

Total hardness in water represents the calcium and magnesium salts, expressed in ppm (parts per million) as calcium carbonate (CaCO3).



As we see in the diagram above, the procedure for measuring the total hardness of water is as follows:

This procedure is applied to all measurements: first, an indicator (generally a few drops) that changes color at the end of the titration (Eriochrome Black in Triethanolamine or Eriochrome Black with a few drops of ammonia added beforehand to raise the pH).

Then, using a calibrated 5 ml plastic syringe (for example), we add the titrant (EDTA, the element that is measured according to its quantity, concentration, and sample size) drop by drop until the color change occurs.

Using the amount of titrant in milliliters, multiply by a factor that depends on the concentration of the titrant.

Normality, that is, the fraction of the molecular weight in grams dissolved in a 1-liter solution of distilled water; if we say N/10 or normal 10, it is the molecular weight of the titrant divided by 10 and dissolved in the solution with distilled water up to 1 liter.

The other factor that determines the factor is the amount of sample taken for analysis; the smaller the sample, the higher the calculation factor.

See the table at the beginning of this chapter.

It is very important that the water is clear; otherwise, filter it with filter paper.

When measuring phosphates, pH, and sulfites, the guide is the color that develops in the test tube containing the sample or on the filter paper immersed in the sample.

Firewood adapted boilers

LAS CALDERAS ADAPTADAS A LEÑA (EUCALIPTOS).

CARLOS W. THOMASSET

Locomotora a leña "CORAZON DE FUEGO"

Caldera de 4.000 Kg hora (carbón)
Un pase (hogar y tubos). Tiro inducido
Quemando leña (eucaliptos) en astillones, baja la producción casi un 50%.
Si quemara F. Oíl, también tendría problemas de combustión: humos, gases no quemados.....

CHAPTER 18: BOILER WATER CONTROL Part 2

LET'S SEE HOW TO MANAGE A WATER TREATMENT BASED ON PHOSPHATES AND SULFITES the oldest effective treatment of a fire-tube boiler with a working pressure of 10 Kg/cm2 (142 PSI)

METHOD FOR PERFORMING RAPID CONTROL ANALYSES OF BOILER PRODUCTS AND PURGES USING PHOSPHATE AND SULFITE BASED PRODUCTS.

1.- Sampling:

Take the boiler water sample using a 1/4 liter (or larger) plastic bottle that can be capped.

Take the sample from the continuous purge blowdown system, purging and rinsing the bottle with boiler water, ensuring you collect water from inside the boiler.

Cool the bottle in air or with water to room temperature (with the cap tightly sealed).

Analyze the boiler water sample as soon as possible.

2- Fill the conductivity meter cuvette 2 or 3 times to rinse it.

Immerse the conductivity meter electrodes, and after 3 minutes of immersion to allow for temperature compensation, measure the total dissolved salts (TDS).

We checked that the conductivity meter's battery was functioning correctly.

If the instrument reads more than 3,000 ppm (parts per million), we must increase the blowdown rate (open the continuous blowdown valve slightly more, continue bottom blowdown, and check levels every 4 hours).

If the reading is below 2,500 ppm, slightly close the continuous blowdown valve.

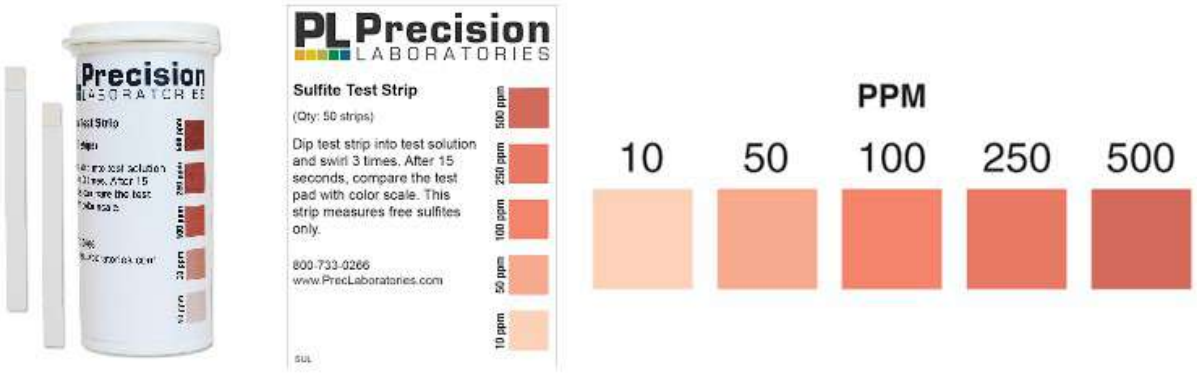
When the water softener is not functioning correctly, dissolved solids decrease, suspended salts (sludge) increase, and phosphates decrease.

Therefore, the softener must be monitored, and it is preferable to maintain low dissolved salt levels in the boiler (so that sludge is purged by bottom blowdown).

Adjust (calibrate) the conductivity meter at least every 3 months.

3- Sulfite Product Control (Oxygen and Chlorine Control):

In the same conductivity meter's container, moisten the sulfite measuring paper for about 5 seconds.



After 30 seconds, compare the reading to the color chart on the container tube. The value should be between 50 and 100 ppm as SO3- (sulfite radical).

If the value is lower than indicated, it could be due to:
- cold feedwater,
- insufficient sulfite being added,
- no sulfite being added during a shift (6 or 8 hours),
- excessive boiler purging (indicated by the conductivity meter),
- condensate being lost or discharged due to a broken line, resulting in excessive makeup water entering the system.

If Sulfite is missing, the amount can be increased if it is thought to be insufficient per shift, or an extra dose can be added if necessary to compensate if the shortage is due to a temporary problem (forgetting, breakage, excessive purging, etc.).

The disappearance of sulfite in the boiler water, or the use of higher quantities than expected, could be due to the introduction of chlorinated water. This should be investigated, since the only protection we have against chlorine (which is highly corrosive) and oxygen is an excess of sulfite.

Increased condensate and higher feedwater temperature reduce the need for sulfite because the boiler water has less oxygen.

In boilers with operating pressures above 40 kg/cm² (569 PSI), sodium sulfite **should not be used** because it tends to decompose, attacking the boiler metal instead of protecting it.

A boiler that is shut down (out of service) should always have an excess of sulfite of more than 100 ppm (and a pH greater than 10.5).

4- PHOSPHATES Control:

(scale, pH, and sludge control if combined with an organic sludge conditioner).

From the boiler water sample, fill the phosphate test tube (empty tube) to the mark (5 ml, second mark) after rinsing with the same water. Then add 4 drops of phosphate indicator from the dropper, cap it, and shake.

Wait 3-6 minutes. The yellow color of the water in the test tube should match that of the indicator sample (100 ppm orthophosphate radical).

If it is lighter in color: this could be due to a lack of PHOSPHATES, improper functioning of the water softener allowing hard water to pass through or introducing hardness through the condensate (in these cases, the boiler water will be cloudier and appear more purged on the conductivity meter), or due to forgetting to add products, or excessive purging (this is indicated by the dissolved salts reading on the conductivity meter).

Pollution can also come from the steam lines when the boiler is stopped (a vacuum is produced).

5- pH Control:

Using pH paper, immerse it in the same cuvette as the conductivity meter for about 5 seconds, then compare the result to the color chart.

The alkalinity due to sodium hydroxide comes from the water softener, which converts all the calcium and magnesium bicarbonates into sodium bicarbonates.

These decompose at the boiler water temperature, leaving sodium hydroxide as the pH of which must be limited to 11.5, given the problem of hydroxide corrosion and, fundamentally, the formation of foam.

This foam contaminates the steam and creates the risk of massive boiler water carryover, leaving heat exchange surfaces under-cooled and at risk of overheating.

This is primarily due to boiler water being present in the steam, which causes water hammer (masses of water impacting against changes in steam direction, especially against heat exchange equipment). Furthermore, the steam becomes a contaminant in boiler water used in various processes (food processing, textiles, etc.).

If the water is acidic, soda (in the form of sodium hydroxide, i.e., caustic soda, in flakes, pearls, or liquid form at 50% concentration, or as sodium ash, which is less hazardous to handle) must be added to achieve a pH above 10.5

This will ensure "free soda" in the boiler water at low and medium pressures. However, as boilers operate at higher pressures, the "free soda" (hydroxide alkalinity) in the boiler water must be reduced.

From 40 kg/cm² (569 PSI) upwards, there should be no "free soda" or hydroxide alkalinity (as at high pressures, soda can attack the high-vaporization heat transfer surfaces).

This type of treatment is called "congruent" and follows a pH curve that decreases from 11.5 as the pressure increases.

This is achieved by using more acidic phosphates (disodium phosphate, Monosodium and as a partial replacement for trisodium phosphate (which contains more sodium); polyphosphates with varying amounts of sodium in their composition can also be used.

The pH should be between 10.5 and 11.5.

If the pH is above 11.5, almost 12, we must perform more purging even if the TDS is below 2,500 ppm. This is generally due to water conditions during dry periods if the water softener is functioning properly.

Also, if purging is insufficient, the pH will be above 11.5.

A pH above 12 makes boiler operation dangerous, potentially causing it to collapse due to poor internal circulation.

If the pH is low, it could be due to: contamination, condensate return, a malfunctioning water softener, or the introduction of hard water (in this case, phosphate levels also decrease, and the water becomes cloudy).

The boiler, when shut down (out of service), should have a pH above 10.5, ideally 11 to 11.5.
If necessary, add a small amount of caustic soda or soda ash along with "product M" (a product sold by C.W.T. Boiler treatment dealers).

Example: Add 100 g of soda per m^3 of boiler water.

The boiler in operation should be analyzed every shift (6 or 8 hours) for softener hardness, and the limit values should be checked once a day or twice a week, or whenever problems are suspected (such as level disturbances, turbidity, etc.).

The boiler when stopped should be checked every 15 days.

If products are added to the stopped boiler, it should be briefly turned on until steam is released from the atmospheric valve, and then flooded.

Rinse all test equipment thoroughly, especially the conductivity meter tank.

When increasing the amount of products, do so in small percentages (20% at a time) and wait a couple of days before retesting.

If you need to correct a product shortage, add an extra measure once (one shift).

For calculating the makeup water, it is assumed that for every 1 liter of fuel oil, approximately 13 liters of water evaporate (for firewood with 25% HBh, this can be said to be equivalent to approximately 4 liters of water per 1 kg of firewood).

Assuming condensate is 30% and purge is 30% of the makeup water (well water with high salinity and alkalinity), we can assume that for every 100 liters of fuel oil, we are adding 100 x 13 x (1-30/100) x (1+30/100) = 1.183 liters.

Rounding this to a makeup water requirement of 1.2 m^3/100 liters of fuel oil.

Using a similar calculation, based on the daily fuel oil consumption, we can calculate the required cubic meters. of makeup water, which allows us to calculate the theoretical amount of Phosphate (depending on the type of phosphate), but generally 30-40 g/m^3, and of Sulfite, generally 60-80 g/m^3, if the feed water temperature is suitable.

These values are then adjusted by the phosphate and sulfite analyses (indicated above).

Purge drain (blowdown) water levels every 4 hours, perform a bottom drain at least once per shift, and drain collectors (gas generator) whenever there is an opportunity for low vaporization (at least once a day, once a week).

Continuous drain is calculated according to the TDS (Total Dissolved Solids) of the makeup water.

If it is well water, the continuous puge drain should be no less than 20% of the makeup water.

In reverse osmosis water with very low salinity, the purge drain should be maintained at 5% to prevent excessive condensate concentration cycles.

Condensate return contains many impurities, from iron oxides to small amounts of other products that penetrate through leaks in the heating surfaces.

Continuous purging allows for TSD adjustment by opening or closing according to the reading, while maintaining the bottom and level purges so that TSD adjustment doesn't have to be done with these purges.

These purges are primarily used to remove sludge (bottom purge) and, in the case of the level controls, to clean the control bodies of sludge and test that they shut off the burner (or the air and induced draft in wood combustion) in case of a low water level (very important for boiler safety).

CHEMICAL LIMITS FOR BOILER WATER:

The limits to be set for the chemical treatment of the elements present in boiler water generally depend on the pressure, but also on the type of boiler and the intended use of the steam (high-quality steam for food processing or textile dyeing).

The main limit is determined by the element that has the greatest impact on the makeup water and the treatment it undergoes.

To determine the blowdown percentage, not only must the total dissolved solids (TDS) be considered, but other factors must also be taken into account, such as: the maximum permissible silica content for the pressure, steam usage, the possibility of silica scaling, highly insulating scale that is very difficult to remove, etc.

In low-pressure boilers, the silica content should generally not exceed 300 ppm as SiO_2 (meaning that if the makeup water has a high silica content, the concentration cycles must be reduced to the maximum established).

We must also consider the total alkalinity (the alkaline salts present in the makeup water, such as hydroxides, carbonates, and bicarbonates), which generally has a total alkalinity limit of 900 ppm as $CaCO_3$ at low pressure.

This means that some well water sources with high alkalinity cannot be cycled for more than 2 to 3 cycles. (This is a very high blowdown.)

The other element to consider is the total suspended solids, which at low pressure should generally not exceed 300 ppm (generally, the water will arrive without suspended solids, but if hard salts enter the boiler, these will precipitate and form suspended solids that will cause problems with internal circulation, foaming, etc.).

These limits, combined, have cumulative effects, and the concentration cycles should be reduced.

All these limits will be lower as the boiler operates at higher pressures or the required steam quality becomes more demanding.

pH is a very important limit. At low pressure, it's advisable not to operate above pH 11.5 (this causes the loss of magnetic oxide, the layer that protects the boiler metal from corrosion), nor below pH 10.5 (a value that also causes the loss of the protective oxide layer due to acidity).

In medium and high-pressure boilers, problems arise that necessitate operating at pH levels lower than 11.5, since
on high heat transfer surfaces, localized areas with high concentrations of free soda (which attacks the metal) develop.

These operating pH values depend on the pressure and type of treatment. Generally, this type of treatment with strict pH control (at values below pH 11.5) is called "congruent chemical treatment" (usually done with phosphates combined with varying amounts of sodium, so that no free sodium or hydroxide alkalinity remains).

We can say that pH is the result of the ratio of alkalinities, and that free soda is equivalent to the phenolphthalein alkalinity multiplied by 2 minus the total alkalinity (methyl orange).

Based on our experience, we can say and advise that in low-pressure boilers (fire-tube boilers, and even more strictly in water-tube boilers), it is not advisable to operate with free soda above 450 ppm (as $CaCO_3$), as this can cause serious internal water circulation problems, endangering the integrity of the boiler (even leading to combustion chamber failure).

In high-pressure boilers, to avoid introducing salts that could accumulate in the boiler water, some methods use volatile elements (meaning they act in the boiler as they pass through, without leaving residues).

Of course, these treatments cannot use water containing elements that could precipitate, accumulate, etc. (the water is completely demineralized, with very high resistivity, silica control, and no room for error in the treatment of the replacement water).

The ASME (American Society of Mechanical Engineers, through its Steam and Water in Thermal Power Systems Committee) has recommended maximum acceptable limits for both feedwater and boiler water (set for water-tube boilers). Let's look at some of these boiler water limits, which are based on pressure.

ASME RECOMMENDED CHEMICAL LIMIT TABLE FOR BOILERS

Pressure (Kg/cm2)	0-21	21-31	31-42	42-53	53-63	63-70	70-105	105-140
(PSI)	0-300	300-440	440-600	600-750	750-900	900-1000	1000-1500	1500-2000
Silica (mg/l SiO2)	≤150	≤90	≤40	≤30	≤20	≤8	≤2	<1
Total Alc. (mg/l)	<350	<300	<250	<200	<150	<100	-	-
Hydroxide Alc. (mg/l)	Not specified.....							
Conductivity (µS/cm)	<3500	<3000	<2500	<2000	<1500	<1000	≤150	≤100

Alkalinity is measured in CaCO3 (calcium carbonate), and conductivity is measured without neutralization (i.e., the boiler water as it is when the sample is taken; if we want to express it as ppm - parts per million - divide the µS/cm by 1.5).

This table is very theoretical; a number of factors must be considered to set the limits, not just pressure (pressure, boiler type, desired steam quality, type of plant to be fed with steam, etc.).

This task should be recommended by the steam treatment specialist based on their knowledge and experience.

In fire-tube boilers, at low pressure, the limits are more generous, depending on the desired steam quality, makeup water quality, type of process to be fed with steam, type of combustion, etc.

CURVE FOR CONSISTENT (COORDINATED) PHOSPHATE-BASED TREATMENT

This graph separates, with a curve, the zone without free soda ash (NaOH) or alkali hydroxide (yellow zone), where medium-high and high-pressure boilers operate, i.e., above approximately 40 kg/cm² (569 PSI),

and the zone with free soda ash (NaOH), where low and medium-low pressures are used, up to approximately 40 kg/cm² (569 PSI).

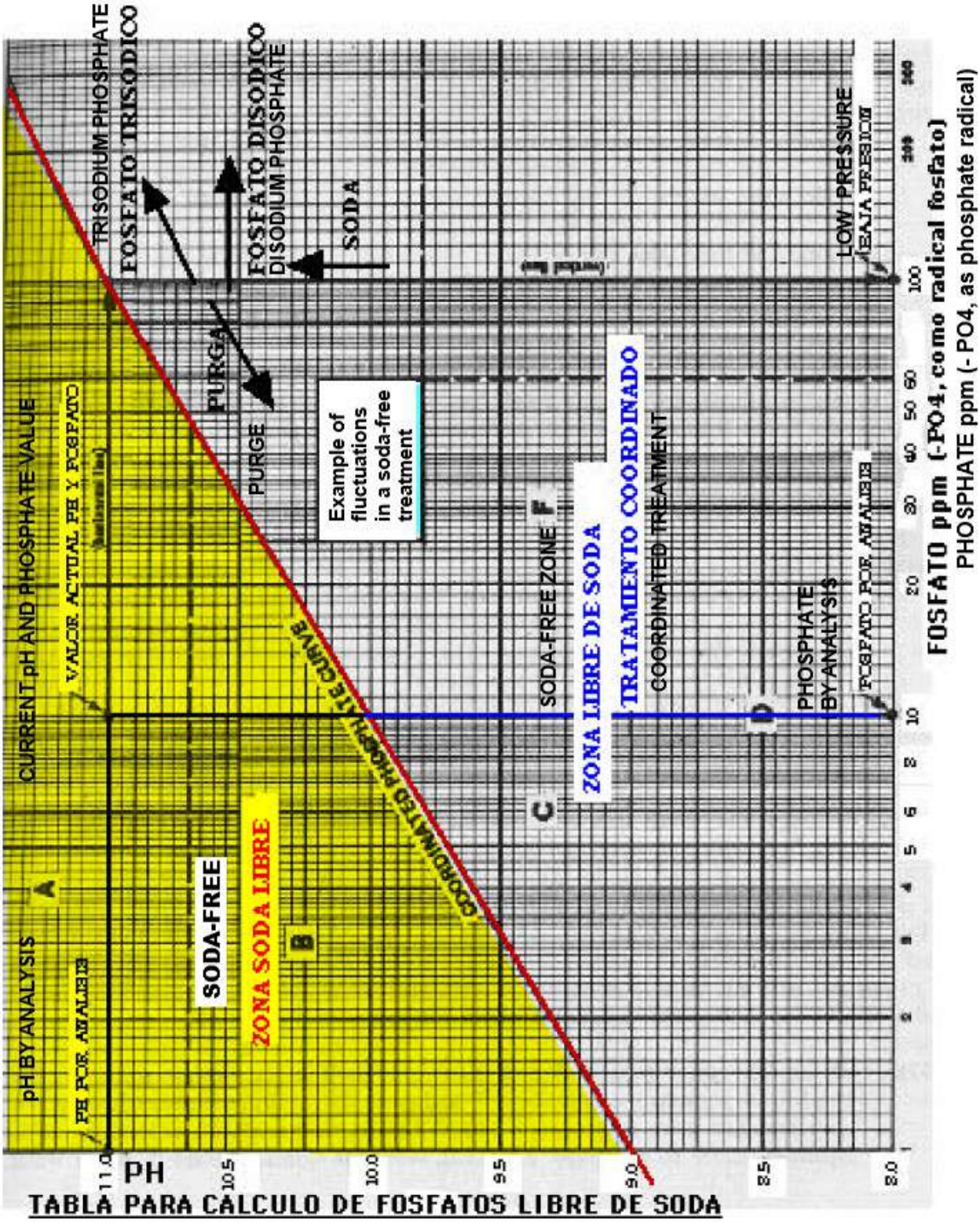


TABLE FOR CALCULATING SODA-FREE PHOSPHATES

The phosphates we can use are Trisodium Phosphate (Na3PO4), which raises the pH along the curve, and Disodium Phosphate (Na2PO4), which follows the horizontal line, maintaining a constant pH.

Sodium Hydroxide raises the pH value vertically.

Blowdown is what lowers the pH (generally, continuous or emergency purge blowdown is the bottom blowdown with the burner off at low pressure.

At medium, high, and high pressures, bottom blowdowns should not be used at full boiler pressure, as water hammer can cause significant damage).

To determine if we have free soda (sodium hydroxide) in the boiler water, we can use not only this chart, but also measure the Phenolphthalein Alkalinity (whose transition pH is around 8.3-8.4).

We also measure the Total Alkalinity (using Methyl Orange, whose transition pH is around 4.3-4.4).

Multiplying the Phenolphthalein Alkalinity by 2 and subtracting the Total Alkalinity gives us the Hydroxide Alkalinity (which is the same as free soda).

The result is expressed as free sodium hydroxide in the same units used to measure the previous alkalinities.

This analysis is very important, since at low pressure it allows us to see if we have problems with the water softener.

A major contributor of sodium bicarbonate to temporary hardness, which,

when entering the boiler, releases the soda and carbon dioxide, which is released with the steam as it decomposes with the heat.

COMMON PHOSPHATES FOR PHOSPHATE TREATMENTS:

Trisodium Phosphate with 12 water molecules $Na_3PO_4 \cdot 12H_2O$ (the most common, with 18.3% phosphate as P_2O_5; it contains the least amount of phosphate)

Trisodium Phosphate with 1 water molecule $Na_3PO_4 \cdot 12H_2O$ (supposedly "anhydrous," meaning dry; it has 39.5% phosphate as P_2O_5 because it contains less water per kg)

Sodium Diphosphate Na_2HPO_4 (anhydrous, since it contains no water molecules, and has a phosphate yield of 48.0% as P_2O_5)

Sodium Diphosphate with 12 water molecules $Na_2HPO_4 \cdot 12H_2O$ (has a yield of 19.0% as P_2O_5)

Sodium monophosphate, there are two, one anhydrous, without water molecules and one with 1 water molecule, they are used relatively little (except as Hexametaphosphate).

Polyphosphates are used to great advantage in phosphate treatment because they do not precipitate with the hard water in the feed tank. Instead, they complex with the water, preventing damage to the feed pumps and valves. Only with the heat of the boiler water do they decompose into basic phosphates, forming phosphate salts.

These are sodium hexametaphosphate $[Na(PO_3)]_6$, sodium tripolyphosphate ($Na_3P_3O_{10}$), and tetrasodium pyrophosphate ($Na_4P_2O_7$). The one containing the least sodium is the first, sodium hexametaphosphate ($[Na PO_3]_6$).

The great advantage of these phosphates is that they are used in most household cleaning products and some in food manufacturing (dairy and others), which indicates their low potential for contamination that could cause harm (except in effluents with large amounts of phosphates that cause algae growth).

It's important to remember that when using phosphate-based treatments, if the pH is very low, the phosphates themselves can cause scaling due to the hardness.

A major advantage of phosphate treatments is that the phosphate not only reacts with the water hardness to form sludge precipitates, but also, with the help of a sludge conditioner to prevent them from sticking to surfaces, they are removed by bottom blowdowns.

Natural organic conditioners (such as cornstarch) are preferable; they are less polluting and their role in corrosion, though not yet fully understood, contributes to keeping corrosion at very low levels.

Boilers with tubes that last for more than 30 years without surface alteration.

The use of sodium sulfite (Na_2SO_3) for oxygen and chlorine scavenging (when the feedwater comes from water treated with sodium hypochlorite) is problematic.

Sodium hypochlorite is highly corrosive in the hot boiler,. While oxygen is corrosive in the cold boiler but corrosive in the condensate system, amplifying the carbon dioxide (CO_2) produced by the decomposition of sodium, calcium, or magnesium bicarbonates at high temperatures inside the boiler.

Its use is limited to pressures of up to 40 kg/cm2 (569 PSI), as it decomposes at higher pressures and causes corrosion in the boiler and the steam and condensate systems.

In boilers operating above 40 kg/cm2 (569 PSI), another oxygen scavenger, not sulfite, should be used.

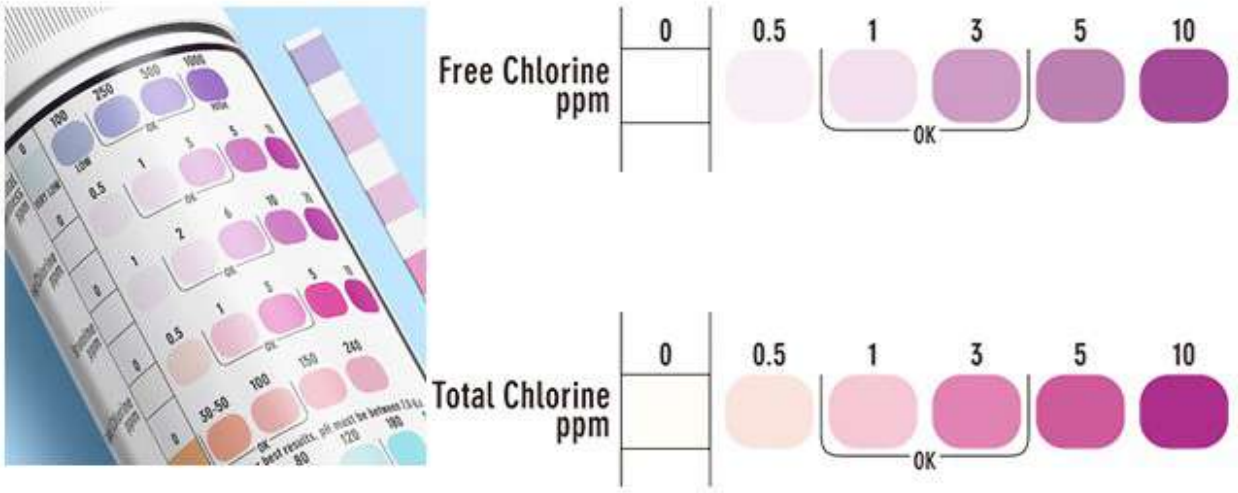
The great advantage of sodium sulfite is that it is not a "pollutant", whereas other oxygen scavengers are.

As a precaution, it is advisable to remove any free chlorine that may be present in the feed water (not to be confused with the chloride ion), as it is highly corrosive unless protected by a sufficient amount of sulfite.

Therefore, it is advisable to have an activated carbon filter to remove the chlorine (from the disinfectant hypochlorite or gaseous chlorine injected into the water for disinfection). Activated carbon absorbs the gases that pass through its highly porous bed. These filters are similar to water softeners in their physical operation.

Although they are backwashed periodically to remove any sludge that the water may contain, the effect of the chlorine trapped in the activated carbon will cause it to deplete over time, requiring periodic replacement.

For this reason, it is essential to verify that the water passing through the carbon filter is chlorine-free (through free or total chlorine analysis).



Regarding oxygen, if we don't have a deaerator (in the feedwater tank), the consumption of sodium sulfite can be very high, causing an increase in Total Dissolved Salts (TSD) in the boiler water, which necessitates more blowdown.

Therefore, if we don't have a deaerator, we must heat the feedwater as close as possible to 100°C (212°F) so that the gases are expelled from the water.

When treating "locomotive" boilers (from railways, for example), it's advisable to consider using tannins (formerly quebracho tree extract) along with the treatment, since these boilers are riveted and can suffer from "fragility" problems in the water, which could cause an accident.

Tannins not only help prevent this, but they also partially protect against oxygen corrosion and are excellent dispersants of deposits that tend to form on metal surfaces.

Today, tannin is synthetic. We have been using it for many years in the boiler of the "Heart of Fire" locomotive (famous by an uruguayan film “CORAZON DE FUEGO” or “EL ULTIMO TREN” year 2002) with great success.

Locomotora a leña "CORAZON DE FUEGO"

The frequency of boiler water analysis should depend on the plant's operation (potential for contamination, such as in a sugar factory where condensate may contain sugar, using alpha-naphthol and sulfuric acid to detect its presence hourly or upon suspicion due to foaming, and other types of polluting factories like cold storage facilities, meat processing plants, etc.).

However, the minimum frequency for boiler analysis is once a week, provided it is a low-risk, low-pressure installation.

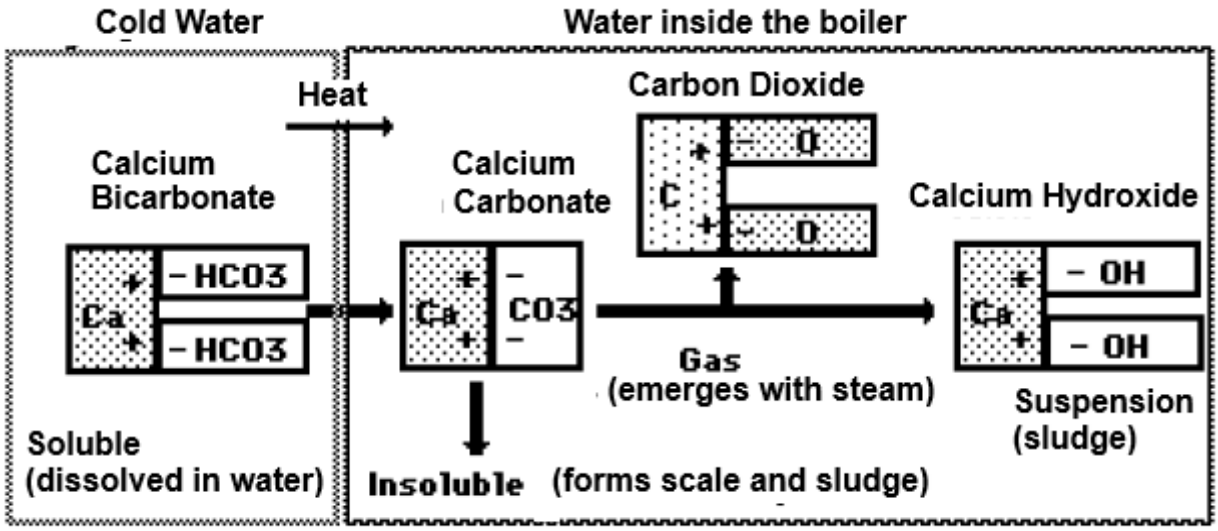
What I support is that the boiler operators should do the basic analyses and the central laboratory should do the control analyses that require more laboratory work, but the boiler operator is in constant contact with the boiler and can take immediate measures based on the analyses he has done or do the analyses when he suspects that something is wrong with the water (such as: level fluctuations, foam, etc.).

Common chemical reactions in boiler water:

These reactions occur when different salts (or the salts themselves due to other factors) come into contact, reacting through the exchange of their atoms or ions to establish a new chemical equilibrium (activated by elements that aid this reaction, such as temperature, pH, catalysts, etc.).

Bicarbonates (sodium, calcium, and magnesium), highly soluble salts very common in boiler makeup water, transform into other salts or gases upon entering the boiler due to the high temperature.

When calcium bicarbonate comes into contact with the hot water in the boiler, the following final reactions occur:



Calcium carbonate precipitates (this is the marble we see in nature), forming scale and sludge.

Carbon dioxide is a gas (the same gas produced by carbon combustion and used to extinguish fires). It dissolves again in cold water, lowering the pH of the condensate and attacking the iron in the pipes in the presence of oxygen.

Calcium hydroxide forms sludge because it is not very soluble (this is the lime we use for whitewashing).

Something similar happens with other bicarbonates, but in the case of sodium bicarbonate, it forms highly soluble carbonates and hydroxides, which are normally dissolved in the boiler, creating the "alkalinity" needed to maintain a suitable pH in the water (provided it is not excessive, resulting in a

very high pH, or in very high-pressure boilers where free sodium is not possible).

WATER HARDNESS

TOTAL HARDNESS = CALCIUM AND MAGNESIUM SALTS
TEMPORARY HARDNESS = CALCIUM AND MAGNESIUM BICARBONATES
Precipitate with temperature (heat)

PERMANENT HARDNESS = CALCIUM AND MAGNESIUM SULFATES AND CHLORIDES

Precipitate with concentration

Other common reactions in boiler water:

Magnesium bicarbonate = Magnesium carbonate + water + carbon dioxide
$Mg(HCO3)2 = MgCO3 + H2O + CO2$

Magnesium carbonate + water = Magnesium hydroxide + carbon dioxide
$MgCO3 + H2O = Mg(OH)2 + CO2$

These salts, containing calcium and magnesium, decompose to form the "temporary" hardness of the water. They are called temporary because they decompose in the presence of heat.

However, there are also salts that form the "permanent hardness" of the water, which, added to the "temporary hardness," forms the "total hardness" of the water.

These salts are:

Calcium sulfate ..... $CaSO4$, Magnesium sulfate ..... $MgSO4$
Calcium chloride ..... $CaCl2$, Magnesium chlorides..... $MgCl2$

They react with other salts:

Magnesium chloride + water = Magnesium hydroxide + hydrochloric acid
$MgCl2 + H2O = Mg(OH)2 + 2\ Hcl$

This reaction is very corrosive due to the chloride ion, but in a properly treated boiler the following occurs:

If there is a water softener, it exchanges the Mg outside the boiler; if this does not happen, it will react with the alkalinity of the boiler due to the sodium:

Magnesium chloride + Sodium hydroxide = Magnesium hydroxide + Sodium chloride

$MgCl_2 + 2\ NaOH = Mg(OH)_2 + 2\ NaCl$

Sodium chloride is a very stable salt, but it is corrosive at high concentrations (it is table salt). We use it as a tracer to monitor purge blowdown by measuring the chloride ion (to establish concentration cycles).

Calcium and magnesium sulfates are more prone to scaling, as their saturation decreases with increasing temperature.

Therefore, the hardness must be removed before it enters the boiler, or non-scaling sludge must be formed with appropriate internal treatment.

For example, with phosphates:

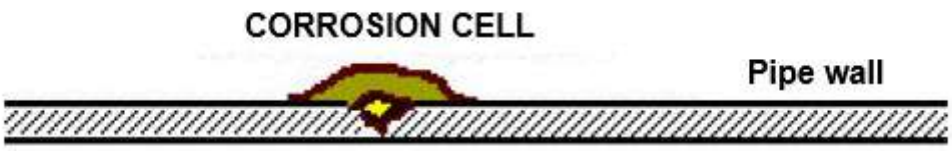
Calcium sulfate + Trisodium phosphate = Calcium phosphate + Sodium sulfate

$3\ CaSO_4 + 2\ Na_3PO_4 = Ca_3(PO_4)_2 + 3\ Na_2SO_4$

With sufficient free alkalinity, a non-scaling calcium phosphate is formed, which precipitates as sludge, and a sodium sulfate salt that does not produce scale or sludge.

Calcium chloride + Trisodium phosphate = Tricalcium phosphate + Sodium chloride
$3\ CaCl_2 + 2\ Na_3PO_4 = Ca_3(PO_4)_2 + 6\ NaCl$

Similar reaction to the previous one.



MOST IMPORTANT OXYGEN CORROSION: "PITTING"

There are many more reactions related to the salts present in the water and those we add to counteract their effect.

Now we will look at some of the reactions used to remove oxygen from the water.

First, the higher the feed temperature, the lower the amount of oxygen the water can hold, and therefore the fewer chemicals we need to use.

The most common chemicals are:

Sodium sulfite + oxygen = Sodium sulfate
$2\ Na_2SO_3 + O_2 = 2\ Na_2SO_4$

In the case of using hydrazine:

Hydrazine + Oxygen = Water + Nitrogen
$N_2H_4 + O_2 = 2\ H_2O + N_2$

This reaction does not form salts that contribute to the TDS (Total Dissolved Salts) of the boiler water, as it forms nitrogen (an inert gas).

Hydrazine has the disadvantage of being considered a hazardous substance (carcinogenic).

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CHAPTER 19: BOILER PURGE (Blowdown)

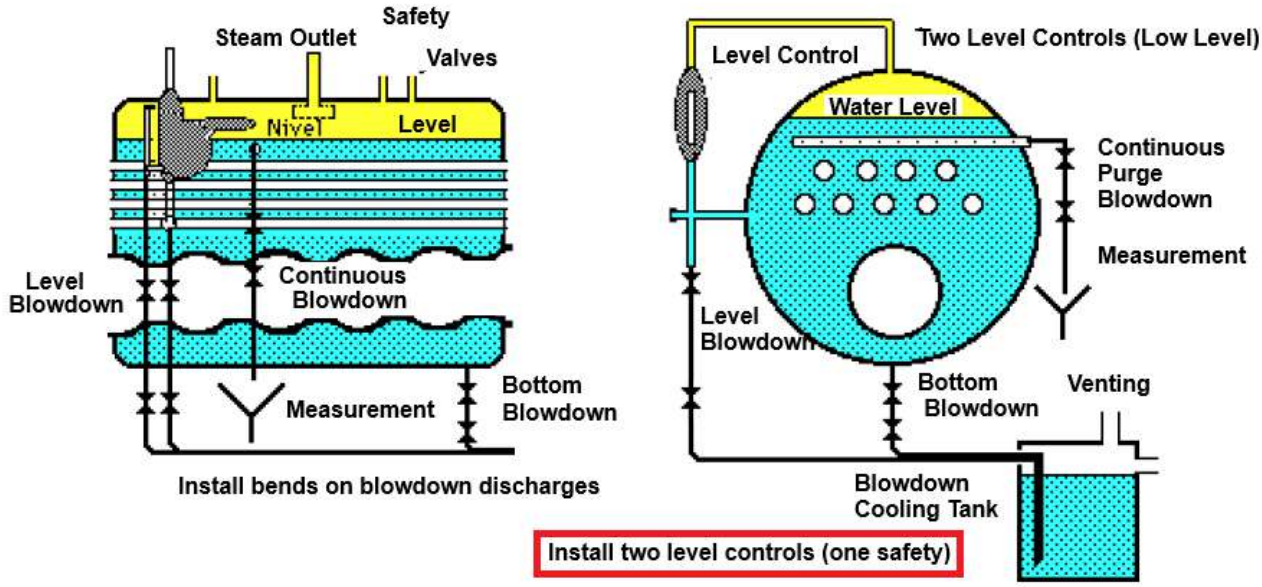
Purging the boiler level is mandatory for safety reasons (every 4 hours). It removes any sludge that may have accumulated in the boiler chamber and very little water, given the short extraction time.

However, it is crucial to verify that the burner shuts off during purging.

In some plants, this affects the timing of purging. To avoid shutting down the boiler, **in some cases it can be so critical that a device is needed to test the level control.**

This device does not allow the boiler to be shut down if a **temporary override button is pressed**, but it does allow the system to be tested.

Extreme caution must be exercised when implementing this type of system. There must be no possibility of the burner shutdown system being permanently disabled, even due to a system failure.



Bottom blowdowns cannot always be performed at any time (never in manifolds, gas generators, etc., with the burner lit, as this could interrupt internal circulation and burn the manifold or gas generator).

In the boiler body, it depends on the pressure, the diameter of the blowdown, the type of boiler, etc.

However, it is always advisable to perform bottom blowdown with the burner off and, if possible, with the steam outlet closed.

In low-pressure boilers (10 kg/cm² - 142 PSI), perform short, repeated <u>blowdowns at full pressure</u>, allowing sludge to accumulate at the purge blowdown outlet.

In high-pressure boilers, do not perform blowdown at full pressure, as the purpose of bottom blowdown is to remove sludge (which should settle to the bottom of the boiler) and salts.

The bottom blowdown should have two valves: a safety valve (close to the boiler) and an operating valve for the blowdown.

Open the safety valve fully, then gently blow down the boiler with the operating valve to heat the pipes without risk of breakage. Open the operating valve fully, then close the safety valve after the blowdown is complete, and finally close the safety valve (close to the boiler).

This valve allows for the repair of the operating blowdown valve—which suffers significant wear on its seat due to sludge—in case it becomes damaged while the boiler is running or even gets stuck open.

It also prevents leaks, which result in continuous, unwanted blowdown.

Both valves should be almost full-flow and appropriate according to the standards for their intended function.

Serious accidents can occur when operating the blowdown system if the valves are not suitable, the pipes are not properly installed and secured, and the operation is not performed correctly.

Heat the system gently, opening the operating valve fully, but without causing a shock or water hammer.

Sometimes the mistake is made of installing blowdown valves with very long pipes, seeking the "convenience" of the boiler operator or a supposed "safety."

This is not advisable, since when the blowdown valves are opened, the water inside the pipe accumulates a great deal of "kinetic energy" (1/2 mv², an equation that gives the amount of energy developed, indicating that half the "mass" times the square of the water's velocity becomes dynamic energy).

Because blowdown valves can be closed "quickly," when the water flow is cut off, the mass of water that accumulated this energy develops pressure on the valve and the pipe closest to it. The pressure depends on how quickly the valve closes, resulting in a very high pressure (called "water hammer").

This pressure can cause the valve body or the pipe to burst (this pressure is added to the existing pressure). the boiler has, minus the pressure loss due to pipe friction and something that comes from the elastic expansion of the pipe).

We can say that a blowdown valve operating on a boiler at 15 kg/cm², if it has a pipe approximately 15 meters long and with a 2-inch diameter, can quadruple the pressure.

This pressure, known as "water hammer," often occurs nowadays due to the presence of "ball" valves (most of which are full-flow and quick-operating).

Many water softener bodies, in which these valves are installed, can, when closed rapidly, "increase the internal pressure of the softener," causing the softener body to crack or even explode (especially when made of resins or plastic).

For example, a softener operating at a water pressure of 3 kg/cm² at the end of a long pipe can increase this pressure to more than 15 kg/cm².

To understand this problem with purge blowdown valves, we can imagine that "water hammer" is like "a hammer striking an anvil"—that is, suddenly stopping a mass moving at high speed, like a driver crashing into a wall.

I have witnessed several accidents caused by this type of error throughout my long career in this field. Blowdown valves must be placed as close as possible to the boiler body connection, or serious risks are involved.

The bottom purge blowdown valve must withstand:

1- High mechanical stress (pressure and erosion)

2- A significant thermal shock

3- Full flow (suspended solids)

4- Plated or welded for medium and high pressure applications

5- Double valves are recommended (for greater safety)

6- Pipes securely attached to the structure (allowing for expansion)

7- Adequate capacity for the function

8- Blowdown valves should be located as close as possible to the boiler body connection to prevent "water hammer".

Continuous blowdown is responsible for removing dissolved salts (it has the advantage of being able to run continuously, not affecting production, and being very easy to regulate, etc.).

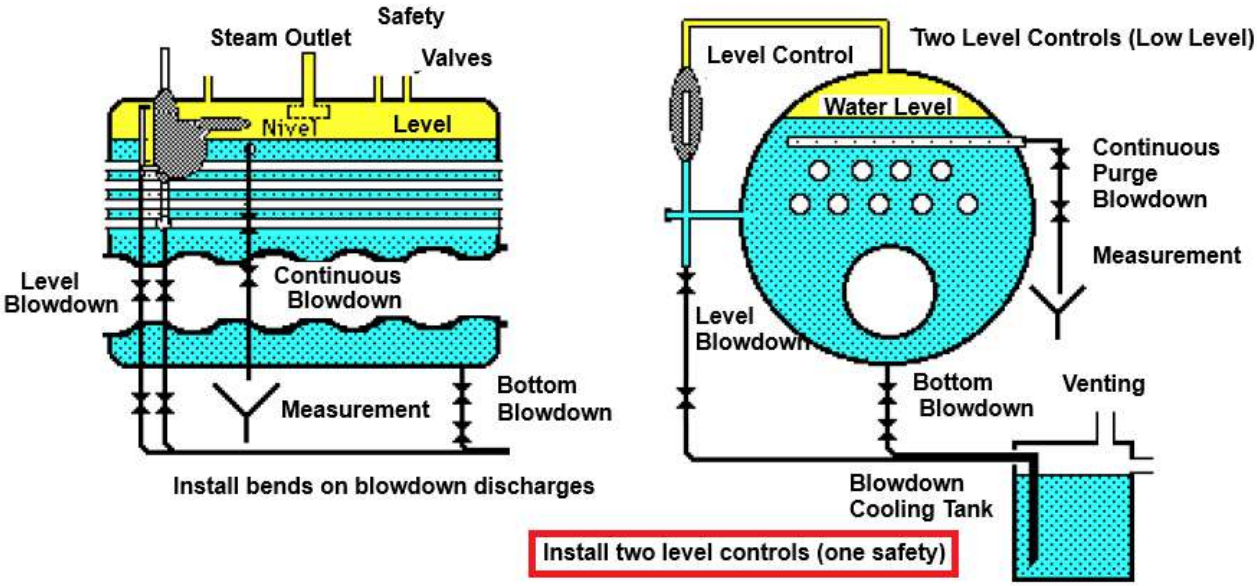
It is advisable that the continuous blowdown system have its own independent discharge (heat can be recovered in a heat exchanger), allowing for visual monitoring and the ability to volumetrically measure the volume of water being discharged per minute.

However, calculating the total purge percentage is crucial, as it allows you to determine the liters per minute of continuous purge. Plus water purge lost in level purges—approximately 20-40 L per level—and bottom purges, which vary but generally do not exceed 80-150 L per normal bottom purge.

TOTAL PURGE = BLOWDOWNS AT EACH LEVEL + BOTTOM + CONTINOUS

This value can be calculated by determining the water surface area in dm² and multiplying it by the level drop in dm after the blowdown, assuming the feed pump has not started.

Example:
A 2000 kg/hr fire-tube steam boiler with a water surface area of 25 dm x 12 dm = 300 dm², the level drops 0.2 dm, or 2 cm, so the "blowdown" water is 300 dm² x 0.2 dm = 60 L per blowdown. As you can see, not much water is removed by the blowdown.



It is advisable that the continuous purge blowdown system have two valves: one against the boiler for complete opening and closing (start and end of the workday), and another valve (further out) to regulate the flow rate of water to be purged.

This second valve should have a suitable, hard seat, such as chrome-nickel, with a needle-type closure or similar, regulating a small flow rate, which generally varies between 0.3 L/min and 30 L/min.

The continuous blowdown should be regulated according to the pH, TDS, or other established maximum limits.

Let's look at the calculation under different circumstances.

When there is an excessive and uncontrollable purge, the cause should be investigated as water leaks from the purge valves (check if the pipe is hot, approximately 1 meter from the last valve; if so, it is clear that water is being lost).

When there is a lack of purge, it is clear that for some reason more water with salts than normal is being added (here the problem could be due to: loss of condensate that was being recovered, a change in water quality, such as the introduction of well water instead of surface water, generally potable water, etc.).

But it could also be that for some reason the flow rate of the bottom or continuous purge is lower than it was, due to an obstruction.

In the case of continuous purge, measuring the volume of water per minute is very important.

At the bottom valve, you should observe how much the visual water level drops, since the purge makes "a lot of noise" due to the "flash," but its volume may have decreased due to an obstruction.

Calculating the Purge Blowdown Percentage:

Since the water replenished in a boiler contains a certain amount of salts, and other salts are added (chemical treatment), it is important to establish a blowdown schedule to remove the excess salts accumulated in the boiler water (the limit will be set by the maximum permissible total dissolved salts or by some of the limiting factors: pH, alkalinity, chlorides, silica, etc.).

Purge blowdown procedures include both bottom blowdowns (which remove sludge and dissolved salts) and continuous blowdowns (which are used to maintain the maximum dissolved salt limit).

Every 4 hours level blowdowns (a minimum of two switches, one for operation and a second for safety) are performed to verify the burner shutdown.

The blowdown percentage can be calculated or measured based on the makeup water in different ways:

1- Considering chlorides (chloride ion).

Since chlorides in water are difficult to precipitate, by measuring the chlorides in the makeup water and the boiler water, we can establish:

Cl a.c. (chlorides in the boiler water),
Cl a.r. (chlorides in the makeup water = condensate + makeup water).
We measure in ppm as chloride ion (Cl-).

Cl a.c. ÷ Cl a.r. = Cycles of Concentration

Cycles of concentration are equal to the number of times the makeup water has been concentrated.

Simple example: if we evaporate 1 liter of water down to half a liter, the concentration of all the salts will double. That is, if the chlorides were at 20 ppm, they will become 40 ppm.

So in this example; 40 ÷ 20 = 2 cycles of concentration.

In the boiler, the total amount of water remains the same, but the salts become more concentrated as the incoming water evaporates.

The blowdown percentage on makeup water will be:

(1 ÷ concentration cycles) x 100 = % Blowdown on makeup water

Example:
Boiler water with chlorides at Cl (boiler water) = 200 ppm
Makeup water from OSE (the company that supplies drinking water in Uruguay) at Cl (makeup water) = 20 ppm

We will have 200 ÷ 20 = 10 concentration cycles and the blowdown percentage on makeup water is (1 ÷ 10) x 100 = 10% blowdown.

This means that 10% of the water that must be added is removed through blowdown or losses in the blowdown valves (as boiler water).

This method measures the amount of blowdown, but does not define it

.

2- If we wanted to establish the approximate percentage of blowdown based on TSD,
we would perform the following calculation:

Maximum total dissolved solids in the boiler (Max. TSD).....ppm.
Total dissolved solids in the makeup water (Rep. TSD).....ppm.
Total chemical treatment per m^3 of makeup water (g/m^3) of salts.

Cycles of concentration = Max. TSD ÷ (Rep. TSD + Treatment g/m^3)

The inverse of the cycles of concentration multiplied by 100 will give the approximate percentage of blowdown on makeup water (since some salts will tend to decompose).

Example:
Maximum limit of total dissolved salts in the boiler at 10 kg/cm^2 (142 PSI pressure):
-Max. TDS = 3000 ppm,
-Softened OSE water with the same TDS = 240 ppm,
-150 grams/m^3 of chemicals (polyphosphates, sulfites, etc.) are added per cubic meter of water.

Approximate concentration cycles = 3000 ÷ (240 + 150) = 7.7 cycles
Blowdown percentage = (1 ÷ 7.7) x 100 = Approx. 13%

This means that we must "blow" approximately 13% of the softened water we add.

That is, if the boiler consumes 2000 liters... For every hour of softened O.S.E. water, ***we must purge 2000 x 13÷100 = 260 Liters per hour****.*

Since the amount of water lost through bottom and level blowdowns is relatively small, we must use continuous blowdown because:

One bottom blowdown releases approximately 50 to 100 liters per session.

One level blowdown (2 levels) releases 20 to 40 liters per session.

If the boiler is blown 3 times per shift (8 hours), this means, taking the higher values (100 + 40) x 3 = 420 liters.

However, since we must blow down the boiler per shift: 260 liters/hour x 8 = 2080 liters.

The difference is 2080 - 420 = ***1660 liters that still need to be blown****.*

Either we do many bottom purges (which is not practical and the heat cannot be recovered) or we establish a continuous (surface) purge, which will "pull" per minute: 1660 /(8 x 60) = ***3.4 Ltrs./ minute****. (we can measure it with a jug if we recover the heat; after cooling there will be no flash steam).*

Calculation of feedwater consumption:
1st case, without condensate return.

Given a heavy fuel oil boiler that consumes 500 liters of fuel oil per day for 10 hours of operation. The pressure is 10 kg/cm² (142 PSI) of saturated steam, and the feedwater at 20°C (68°F) is without condensate return (O.S.E. Montevideo, softened, with 240 ppm TSD and a chemical treatment of 150 g/m³, previous example).

The boiler operates at 50% of its nominal capacity. Its efficiency at LHV without blowdown (100% condensate return, obviously not realistic) is estimated to be 82%, and then with blowdown and no condensate return, 79%.

Let's calculate, taking the values from the previous tables approximately:

1-Without purging (100% condensate return, an ideal case)

Heat required to vaporize 1 kg of water (664 - 20) = 644 kcal/kg of steam.

Available heat per kg of fuel oil: 9700 x 82 ÷ 100 = 7,954 kcal/kg. Steam yield per kg of fuel oil without purging: 7,954 ÷ 644 = 12.35 kg/kg.
Purge is always necessary for safety (levels, bottom, etc.).

Since fuel oil weighs less than water, we consider 1 liter of fuel oil to be 0.960 kg.
Therefore, 500 liters... The amount of fuel oil will be 500 x 0.960 = 480 kg in 10 hours.
The amount of steam per hour will be 480 x 12.35 ÷ 10 = 593 kg/h of steam.

Without blowdown, we should feed 593 liters of makeup water per hour.

2-Without return condensate (a real case):

The blowdown will be: C.c. = 3000 ÷ (240+150) = 7.7 cycles, which will give a blowdown percentage of approximately (1÷7.7) x 100 = 13%.

This means that we must blow down approximately 1 x 13 ÷ 100 = 0.130 liters for each liter of feedwater.

To calculate the evaporated water, we use = (9700 x 79) ÷ (644 x 100) = 11.9 kg/kg of fuel oil.

Feedwater = steam + blowdown = steam + feedwater x 1 ÷ C.c.

Feedwater = steam ÷ (1-1/C.c.) = 13.67 L per kg of fuel oil.

Since we are flushing hot water at the steam temperature, this heat must be subtracted from the heat supplied by the fuel: 0.130 x (185-20) x 13.67 = 293 kcal/kg of fuel oil.

Recalculating the amount of fuel lost through blowdown due to the absence of condensate: 480 x 293 ÷ 9700 ÷ 79 x 100 = 18.35 kg of fuel oil wasted through blowdown in 500 L of fuel oil used.

Average steam output (kg/hour): 11.9 kg x 480 kg ÷ 10 h = 571.2 kg/hour.

As condensate return increases, water replenishment decreases, and steam production per kg of fuel increases.

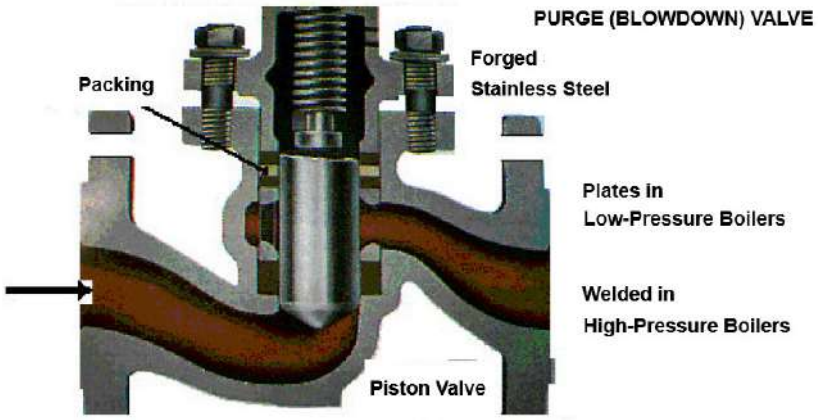
The hourly feed without condensate return will be 13.67 x 480 ÷ 10 = 656 liters of water per hour (approximately).

The total water to be purged without condensate return in 10 hours will be (13.67 - 11.9) x 480 = 849.6 liters.

When there is a percentage of return condensate: Feed Water = Steam x % Cond + Make-up
Feed Water = Steam x % Condensate ÷ 100 x [1 + 1 ÷ (1 - 1 ÷ C.c.)]
50% condensate, with previous salt values and an efficiency of 79.5% L.C.I.
Water evaporated = 9700 x 79.5 ÷ 644 ÷ 100 = 11.97 Kg/Kg of F.Oil
Feed Water = 11.97 x 50 ÷ 100 x [1 + 1 ÷ (1 - 1 ÷ 7.7)] = 12.86 L/kg of fuel oil

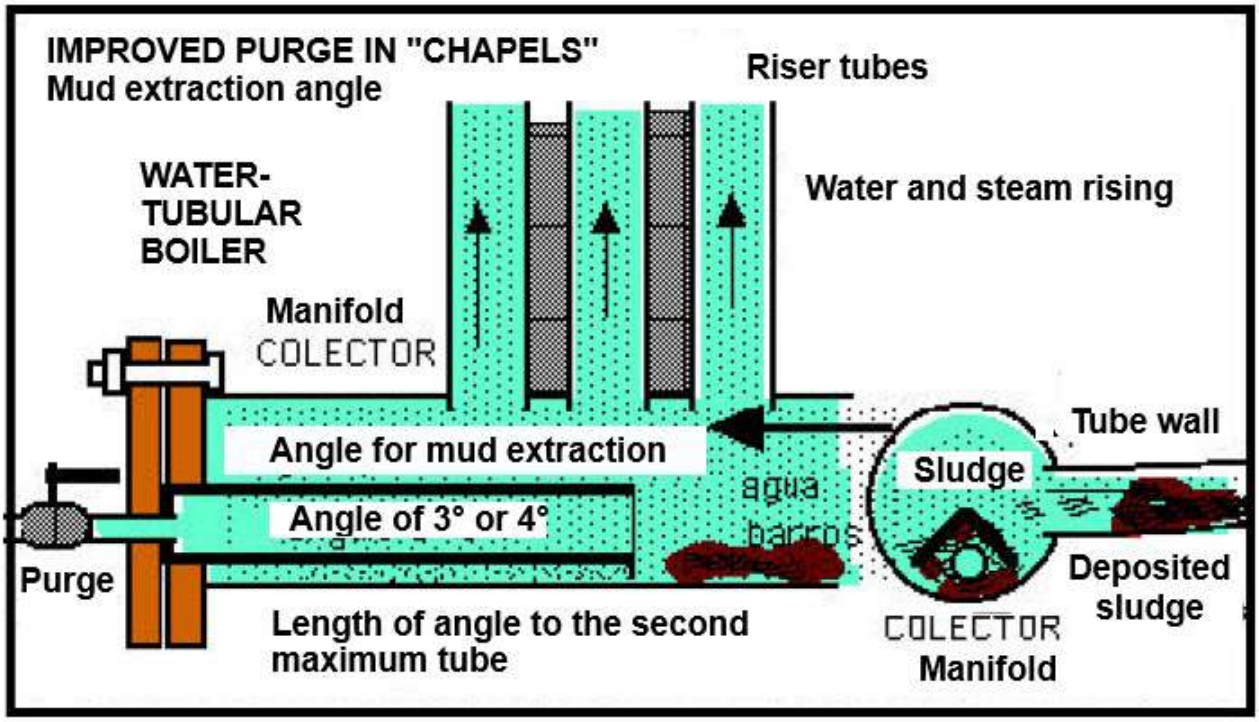
Total water to be purged in 10 hours (12.86 - 11.97) x 480 = 427.2 L

As you can see: greater condensate recovery means less purging, greater performance (efficiency).



“CHAPEL” CHAMBERS (COLLECTORS) PURGE

The "chapels," both the water-tube combustion chambers in "direct-fired" boilers and the water-tube "rear chapels" of "semi-wet bottoms," when there is no "external" chemical treatment to soften the water (water softener, reverse osmosis, or chemical precipitation softening), that is, to remove calcium and magnesium salts or transform them into sodium salts, the "internal" chemical treatments cause the precipitation of scale-forming salts as "removable sludge" through the purges.



IMPROVED PURGE IN "CHAPELS" Sludge extraction angle

When sludge forms inside the boiler, the bottom and header blowdowns must be able to remove it. Therefore, blowdowns must be installed in strategic locations, both at the bottom of the casings and in the headers.

When there are "chapels" (sludge chambers), if these lack blowdowns, sludge will accumulate in the side pipes and the headers themselves.

Even with blowdowns, if they are not of sufficient diameter and do not have an adequate slope, sludge will accumulate in the side pipes and in the headers. Angles (3" to 4", tapped on the flange, leaving a 10 mm gap from the bottom of the header) create a suction effect from the bottom of the header.

This boiler model generally does not have this angle, but it is advisable to install it, especially if it lacks blowdowns.

The purging of the collectors of water-tube boilers must always be done with combustion at minimum or turned off (purge once per shift if there is sludge formation).

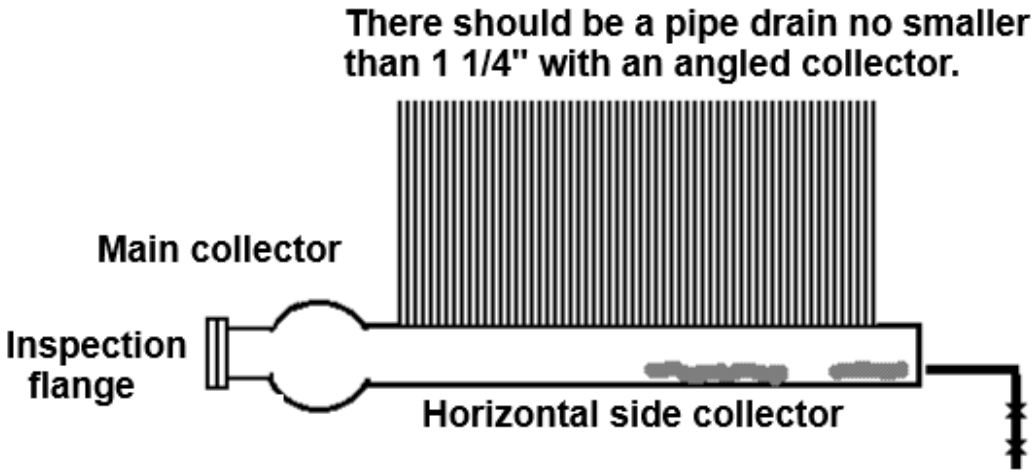
This white paper is not part of original “Pequeño Manual del Foguista 2011”, but was an interesting finding in Apple Macintosh Hard Disc CWT computer;

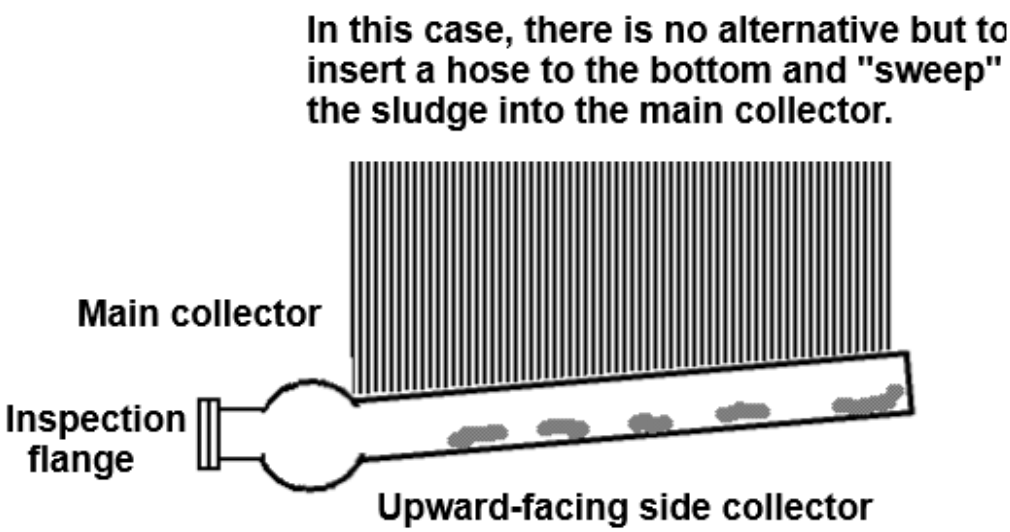
LOW SLUDGE COLLECTORS

Nothing is as important in a boiler as proper internal circulation.
In every horizontal collector, a blowdown should be located at the end of the flow if there is no outlet for the sludge unavoidable in the treatment process, especially the hulls.

When the collector is horizontal, adding a blowdown at the end is not a problem, and it should be able to remove the sludge.

The problem arises when these collectors are improperly designed with an upward slope. In these cases, the blowdown is ineffective, so the boiler must be opened periodically (depending on local conditions) and manually cleaned.

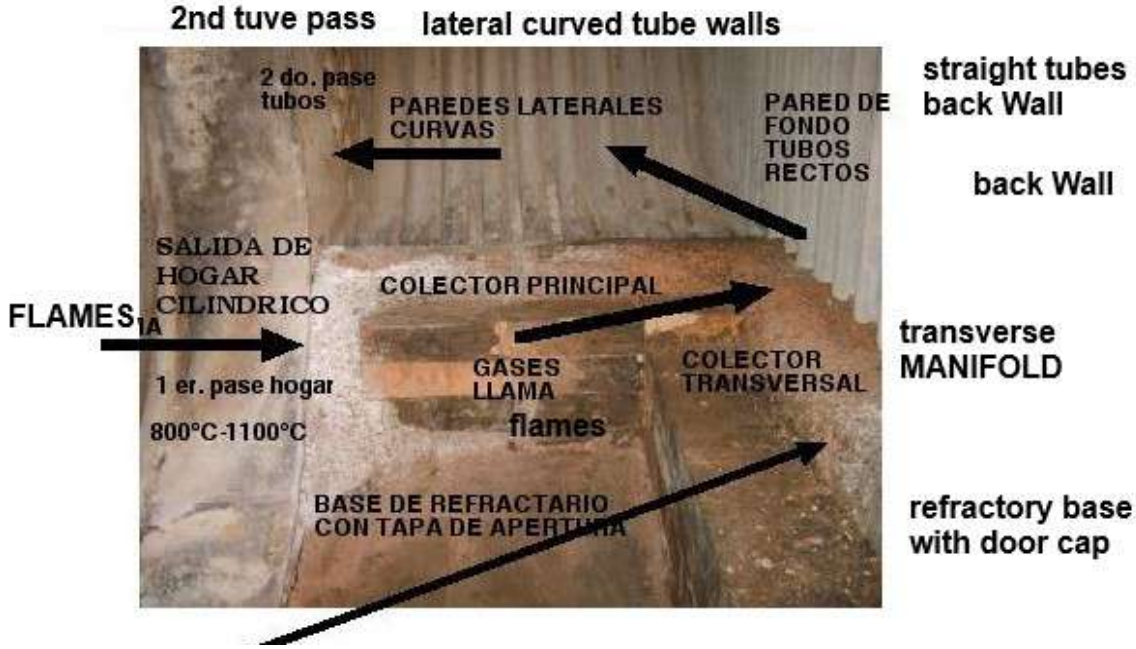

There should be a pipe drain no smaller than 1 1/4" with an angled collector.
Main collector
Inspection flange
Horizontal side collector


In this case, there is no alternative but to insert a hose to the bottom and "sweep" the sludge into the main collector.
Main collector
Inspection flange
Upward-facing side collector

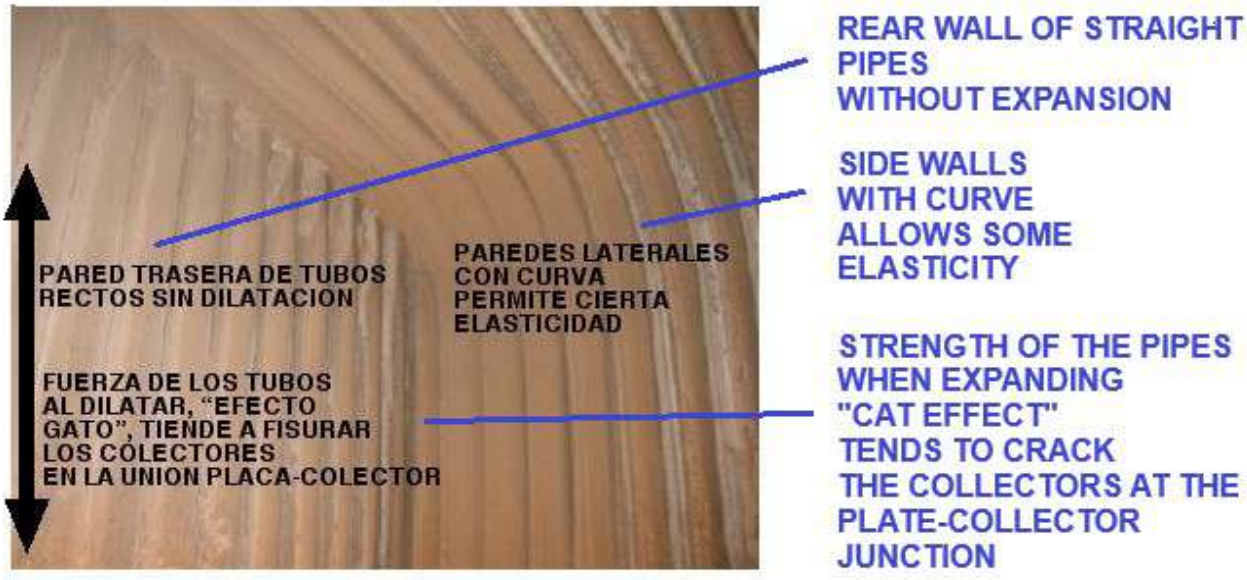
Also this white paper is not part of original “Pequeño Manual del Foguista 2011”, but was an interesting finding in Apple Macintosh Hard Disc CWT computer;

CRACKING PROBLEMS IN REAR CHAPEL COLLECTORS
REAR CHAPEL LAYOUT OF A WOOD-FIRED BOILER (by C.W.T.)

Layout of the tubes in a rear chapel of a wood-fired boiler, showing the curved side walls (which allow for some elasticity) and the straight rear tube wall (which does not allow for elasticity and can cause expansion that creates a "cat effect" on the root of the main collectors, causing them to crack flush with the plate).



The "transverse" collector with the rear wall of the tubes allows the accumulation of sludge that does not exit through the collector purges, hindering internal circulation in the rear wall and increasing the temperature of the straight tubes that expand, "pushing" the collectors towards the crack.


PARED TRASERA DE TUBOS RECTOS SIN DILATACION
PAREDES LATERALES CON CURVA PERMITE CIERTA ELASTICIDAD
FUERZA DE LOS TUBOS AL DILATAR, “EFECTO GATO”, TIENDE A FISURAR LOS COLECTORES EN LA UNION PLACA-COLECTOR
REAR WALL OF STRAIGHT PIPES WITHOUT EXPANSION
SIDE WALLS WITH CURVE ALLOWS SOME ELASTICITY
STRENGTH OF THE PIPES WHEN EXPANDING "CAT EFFECT" TENDS TO CRACK THE COLLECTORS AT THE PLATE-COLLECTOR JUNCTION

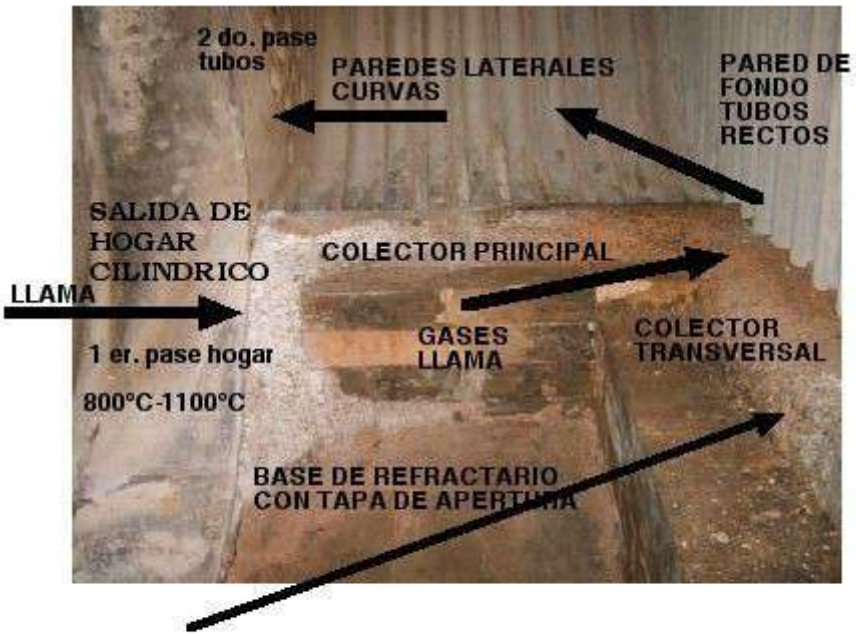
Original White Paper in spanish;

PROBLEMAS DE FISURAS EN COLECTORES CAPILLAS TRASERAS

DISPOSICION DE CAPILLA TRASERA DE CALDERA LEÑA

CARLOS W. THOMASSET

Disposición de los tubos de una capilla trasera de caldera a leña, que muestra las paredes laterales curvas (admiten cierta elasticidad) y la pared trasera de tubos recto (que no admite elasticidad y puede provocar dilataciones que provocan un "efecto gato" sobre la raíz de los colectores principales, provocando la fisura de los mismo al raz de la placa.



COLECTOR "TRANSVERSAL" DE PARED DE TUBOS TRASERA PERMITE ACUMULACION DE BARROS QUE NO SALEN POR LAS PURGAS DE LOS COLECTORES, DIFICULTANDO LA CIRCULACION INTERNA DE LA PARED TRASERA Y AUMENTANDO LA TEMPERATURA DE LOS TUBOS RECTOS QUE DILATAN "EMPUJANDO" LOS COLECTORES A LA FISURA.

PARED TRASERA DE TUBOS RECTOS SIN DILATACION
PAREDES LATERALES CON CURVA PERMITE CIERTA ELASTICIDAD
FUERZA DE LOS TUBOS AL DILATAR, "EFECTO GATO", TIENDE A FISURAR LOS COLECTORES EN LA UNION PLACA-COLECTOR

1996 Photo with C.W.T., our beloved father, a role model to follow. An open book of life, sharing knowledge and experience, something very delicate when dealing with steam boilers, elements with a high risk of fatal accidents. He revealed "unpleasant" experiences that often generated conflicts of interest with boiler manufacturers, industrial plant owners, plant engineers, and accountants who wanted to save money by endangering the lives of boiler operators. But he always had a clear conscience, knowing that nothing was hidden, submitting the corresponding corrective reports to the engineer, the employer, the owner, and the national authorities, in defense of the lives of boiler operators. In Uruguay, there is no union or association of boiler operators, and this lack partly motivated their actions and the writing of this series of books, "The Little Manual for the Boiler Operator," which allowed CWT to influence manufacturers, the purchase and sale of safe new boilers and the dismantling of unsafe boilers as scrap metal, and most importantly, to influence national regulations in Uruguay and the boiler training curriculum at UTU Buceo, the Navy, the Fire Department, and COCAP. Life's paths took us away from the boiler subject (in our case, his son P.J.T.T.) we specialized in hydroelectric power plants, but we were strongly influenced by CWT's human teaching of "not hiding anything", and publishing all knowledge in a formalized manner in technical reports, ranges and maintenance instructions for plant personnel.

Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 19: PURGES (Blowdown)

Fotografía año 1996 con C.W.T., nuestro querido padre, un ejemplo de vida a seguir. Un libro abierto de vida, compartiendo conocimientos y experiencias, algo muy delicado al tratar con calderas de vapor, elementos con alto riesgo de accidentes fatales. Revelación de experiencias "desagradables" que a menudo generaban conflictos de intereses con fabricantes de calderas, propietarios de plantas industriales, ingenieros de planta y contadores que querían ahorrar dinero poniendo en riesgo la vida de los operadores de calderas. Pero siempre con la conciencia tranquila, sabiendo que nada se ocultaba, presentando los informes correctivos correspondientes al ingeniero, al empleador, al propietario y a las autoridades nacionales, en defensa de la vida de los operadores de calderas. En Uruguay, no existe un sindicato ni asociación de operadores de calderas, y esta falta motivó en parte sus acciones y la redacción de esta serie de libros, "El Pequeño Manual del Operador de Calderas", lo que permitió a CWT influir en los fabricantes, en la compra y venta de calderas nuevas seguras y en el desmantelamiento de calderas inseguras como chatarra, y lo mas importante lograr incidir en las reglamentaciones nacionales de Uruguay y la curricula de la capacitación de calderas en UTU Buceo, en la Armada, en Bomberos, y en COCAP. Los caminos de la vida nos alejo del tema calderas (nuestro caso su hijo P.J.T.T.) nos especialiamos en centrales hidroelectricas, pero nos prendio fuerte la humana enseñanza de CWT de "no esconder nada", y publicar protocolizado todo conocimiento en; informes tecnicos, en gamas e instrucciones de mantenimiento para el personal de planta.

CHAPTER 20: CHEMICAL CLEANING OF BOILERS

Chemical cleaning is a very important aspect of boiler maintenance, not only for achieving a good clean, but also because **if it is not done correctly it can damage the boiler's metal and pose risks.**

Chemical boiler cleaning must be performed with sufficient knowledge of which chemical elements to use, which procedures are most appropriate, and with due regard for boiler safety and, above all, the safety of the operators performing the chemical cleaning.

Generally, two types of chemical cleaning can be performed on scaled boilers (if the boiler has not been chemically treated or the chemical treatment is of questionable effectiveness).

The first type we will show has three stages:

1st STAGE: alkaline stage,
2nd STAGE: acidic stage,
3rd STAGE: neutralization and passivation stage.

1st STAGE: alkaline stage

The first alkaline stage prepares the scaled surfaces for penetration by the acid to be used. This stage generally involves boiling with soda ash (and an anti-embrittlement agent), with a free soda content of approximately 2% to 4%.

This is done with 75% steam pressure for about 24 hours, purging the system and ensuring the steam is not used for the industrial plant's consumption.

The other chemical cleaning scenario is when the boiler is scaled, but its chemical treatment, while adequate, was insufficient at times.

Despite being a treated boiler, it allowed scale to accumulate from hard water that entered for various reasons (these scales are generally composed of calcium or magnesium carbonates).

In this case, the first alkaline stage is skipped, and the acid stage is used directly.

2nd STAGE: acidic stage

The most commonly used acid for chemical cleaning is **hydrochloric acid (HCl)**, due to its ease of handling and its strong ability to bind with carbonate deposits.

CAUTION: DO NOT USE HYDROCHLORIC ACID ON BOILER PARTS MADE OF CHROMIUM-NICKEL STEELS (generally high-temperature superheaters).

Several things need to be clear: acid, whatever its type, attacks iron metal unless an "acid inhibitor" is used (e.g., Rodine 60® or another). Formaldehyde was used in the past.

The second thing to keep in mind is that acid works best at a certain temperature (it hardly attacks scale when cold), so generally around 60-80°C (140-176°F).

The third consideration is the reaction time inside the boiler and the theoretical concentration of pure acid at the start of the acid treatment, the concentration it should have at the end, and the final concentration required to complete the acid treatment (which should never exceed 12 hours).

Another consideration is that the burner should not be lit under any circumstances during this acid treatment stage.

And very importantly: when acid attacks iron metal, it produces hydrogen gas (H2), a highly explosive gas, so it is essential to install a good vent (extractor/fan) for these gases at the top of the boiler (such as a connection from a safety valve to the chimney with a pipe of good diameter).

Regarding safety, at all stages, chemicals must be handled using appropriate personal protective equipment (PPE): safety glasses, acid masks, gloves, aprons, and rubber boots.

It is advisable to have a fan that strongly circulates the air in the chemical cleaning work area, and to include a hose with running water to wash away any chemical spills, whether on the floor, the boiler, or the operators themselves (in addition to having buckets of clean water readily available to immediately wash any part of the body that has come into contact with the acid).

It should also be considered that at each stage, the chemicals, previously neutralized, must be discharged into the wastewater discharges or effluent treatment plant of the industrial plant.

Since the first stage is alkaline (water with a high pH will be discharged), while the second stage is acidic, although the acid is consumed, it is generally discharged into the drain still with a certain concentration as pure acid (close to 1% if calculated correctly).

It is recommended that the acid cleaning should be done in about 12 hours and no more, since if it is done for longer, the metal is attacked microscopically, causing it to resemble a porous "pumice stone" (whose holes are not visible to the naked eye, but in a hydrostatic test, it will cause the pipes to "sweat" when subjected to the pressure of the test water for a reasonable time.

The neutralization of the effluents from the acid stage should be done outside the boiler (in a tank or reservoir of the blowdown pit) using the alkaline water from the first stage, if it was done, or using liquid soda or "quicklime" (previously dissolved).

3rd STAGE: neutralization and passivation stage

The third stage, a neutralization and passivation stage, should be carried out similarly to the first alkaline stage, raising the pressure to 75% of the working pressure (24 hours, purging every hour).

However, a passivating agent must be used to cause oxidation of the surfaces, reforming the **magnetic oxide layer** that protects the surface of the boiler tubes and allows a bare iron tube to last so many years.

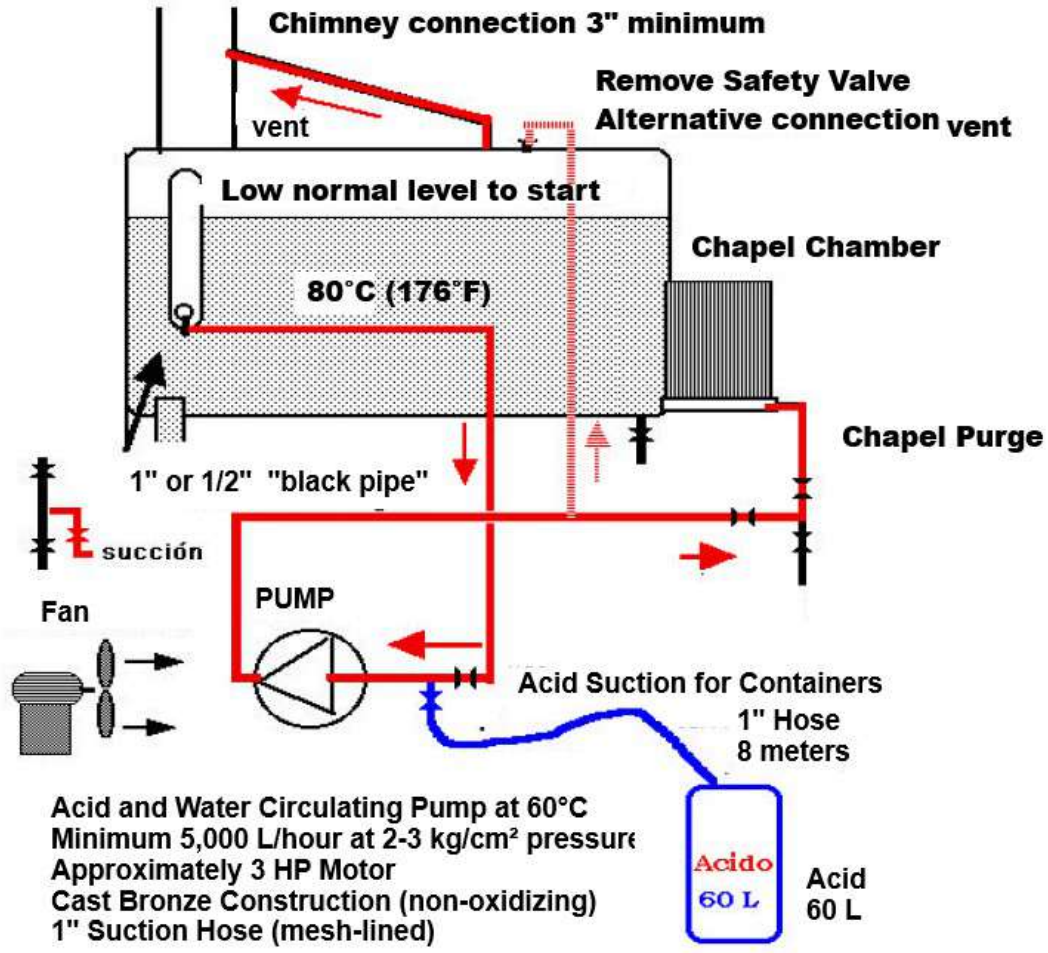
In some boilers, we have far exceeded 30 years and much more, to the point that the tubes wear out first on the flue gas side.

In the acid stage, it is generally assumed that there will be a theoretical need for 5% pure hydrochloric acid (15% commercial acid at 30%-34% HCl) and the inhibitor is usually 1% to 5% of the commercial acid (depending on the acid inhibitor used).

Hydrochloric acid (HCl) is a gas dissolved in water, so at high temperatures it will tend to escape from the water in which it is dissolved (hence the importance of the vents, fans, and masks used).

The preparation of the system, boiler and accessories, is fundamental, since it can be done very crudely by hand (acid from containers is added through the manhole) or more correctly (for safety) by means of acid pumps or simple circulation pumps (not made of stainless steel) that take water from the same boiler and discharge into another area of the boiler, with a connection to the suction that allows the acid to be drawn directly from the acid containers.

Let's look at the diagram:
The circulating pump is actually more than just for introducing the acid safely and easily; it doesn't need to run for the entire 12 hours of acid cleaning, since what actually circulates and agitates the acid inside the boiler are the "bubbles" (CO_2) released from the acid's attack on the carbonate scale..



As mentioned, the process starts with a water temperature between 60°C (140°F) and 80°C (176°F), preventing the burner from igniting with acid inside the boiler.

While the minimum amount of acid required is 15% commercial hydrochloric acid, we must consider that if the boiler is heavily scaled, we should have extra acid on hand to replenish it if, after adding the acid in approximately 1 to 2 hours, the concentration reaches 4% pure acid.

When the acid is first added, very violent reactions can occur between the acid and the scale, causing a rapid rise in the boiler water level due to bubbles.

This can sometimes be so violent that water can be expelled through the boiler openings (e.g., with the manhole cover open), soaking people and damaging equipment.

Therefore, the acid must be added slowly and carefully to prevent the level from rising too high (which is why the process begins with the boiler water level at its lowest point, but ensuring the tubes remain submerged).

To measure the HCL acid concentration, we use Methyl Orange (pH approximately 4.3) as a pH indicator and "titrate" with calibrated sodium hydroxide to a value appropriate to the sample size to obtain the percentage of pure hydrochloric acid.

N/1.33 sodium hydroxide directly yields 1% of acid as HCl for each cm^3 of sodium hydroxide consumed to change the Methyl Orange indicator to a percentage of pure acid when the sample being analyzed is approximately 5 cm^3.

For example: in a 5 cm^3 sample of boiler water diluted to 50 cm^3 with distilled water, a few drops of Methyl Orange are added, producing a dark, almost reddish color. When adding dropwise, while swirling in a Herlenmeyer flask with N/1.33 sodium hydroxide until the color changes to a nearly clear color, the volume of N/1.33 sodium hydroxide in cm^3 directly indicates the percentage of HCl.

Obviously, one must be very experienced in taking this measurement before the task of performing a chemical cleaning of the boiler with hydrochloric acid (HCl). This type of chemical cleaning cannot be improvised, as it poses a risk to people on duty there, and might damage the boiler itself.

The end of this acid stage is observed after approximately 9 hours. This is indicated by the agitation of the boiler water (the formation of CO2 bubbles). If the water is not agitated by these bubbles, it means that the acid's action on the scale is in its final phase.

The acid concentration is measured every half hour, and when it is the same concentration after a half-hour interval, this acid stage is considered complete.

Generally, if the amount of acid was calculated correctly, at the end of the operation the acid concentration will be 1% or less as pure HCl.

The operation should be completed in less than 12 hours, as continuing the acid process for longer will damage the boiler metal.

To dispose of the acid as effluent, remember to neutralize it (using soda ash or quicklime).

The danger at this stage is that in the final part of the operation, if the boiler is not properly vented, hydrogen gas (H2) can accumulate from the reaction of the acid with the boiler metal. This gas is highly explosive at low concentrations (while there is a lot of activity with CO2 formation, the danger is lower since it is diluted by the CO2).

That is why it is important to connect a gas exhaust system
from a safety valve to the chimney (which will create a good draft to vent the gases to the atmosphere).

Once the acid stage is complete, the inside of the boiler must be hosed down with water through the manhole.

Alternatively, the boiler should be filled and emptied approximately twice to remove residual acid from the walls, but primarily to remove the many deposits that the acid has released but not dissolved.

This stage must be carried out as quickly as possible to prevent oxidation in the presence of acid, which can cause significant corrosion (for example, if the boiler is left empty of acid in contact with the atmosphere for several hours).

The neutralization and passivation stage must be carried out immediately (using 2% to 4% soda ash for neutralization and passivating agents such as nitrites, borates, etc.).

The passivating agents form a new (very thin) protective layer of magnetic oxide on the iron metal surfaces.

Once the boiler has been inspected, it is filled with treated water and treatment chemicals, a hydraulic leak test is performed, and if everything is in order, the sealing gaskets are replaced, the covers are closed, the boiler is started up, and the covers and caps (which loosen under internal working pressure and heat) are retightened.

This operation must be carried out by someone with experience to avoid losing a cover or cap that could endanger the operator.

The safety of chemical cleaning must consider not only the operators involved, but all personnel who may be in the area (there are very irritating gases that, if not diluted and vented properly, contain hydrochloric acid as a gas, since hydrochloric acid is actually a gas dissolved in water, at its maximum commercial concentration it is 34% acid in water).

Although hydrochloric acid is not very aggressive to humans (in its liquid state, i.e., when the hydrochloric acid gas is dissolved in water), protective equipment must be used, especially respirators that absorb the acid (it greatly affects the respiratory tract because it is a highly irritating gas). Eyes should also be protected with appropriate goggles.

It is advisable to have a running hose with water available during acid operations and a bucket of clean water to wash off immediately if someone is affected by the acid. An eyewash station should also be available in case of splashes in one or both eyes, even if protective goggles are worn.

Since the eyes are very sensitive, even if they are washed immediately with clean water, irritation may remain, requiring an ophthalmologist's attention.

If the respiratory tract is affected, one should move to areas with uncontaminated air for minor irritations. Medical attention is necessary if the irritation is more severe.

Especially in sensitive people, such as asthmatics, whom we advise against doing these types of tasks.

Caution is advised when using caustic soda (sodium hydroxide flakes or pearls), as it can rapidly irritate the skin and eyes.

If contact occurs, wash immediately with water and seek medical help.

It is best to use caustic soda already diluted to 50% (liquid soda) or soda ash, which are less aggressive.

Adding caustic soda to water also releases highly caustic fumes that affect the respiratory system.

Therefore, it is essential to add the soda to the water (not the water to the soda) in a well-ventilated area (with a fan) and while wearing appropriate protective gear (goggles, masks, gloves, etc.).

If you are inexperienced with these procedures, it is advisable not to attempt them without professional assistance (from someone knowledgeable in the subject).

CHEMICAL CLEANING EXAMPLE:

Chemical cleaning of boiler (15 Ton/h, 12 Kg/cm2 = 172 PSI) scaled by use of "mixture" of well water and surface water (the operator loses track of the water quality and with it the regeneration rate of the water softener and the proper dosage of chemicals).

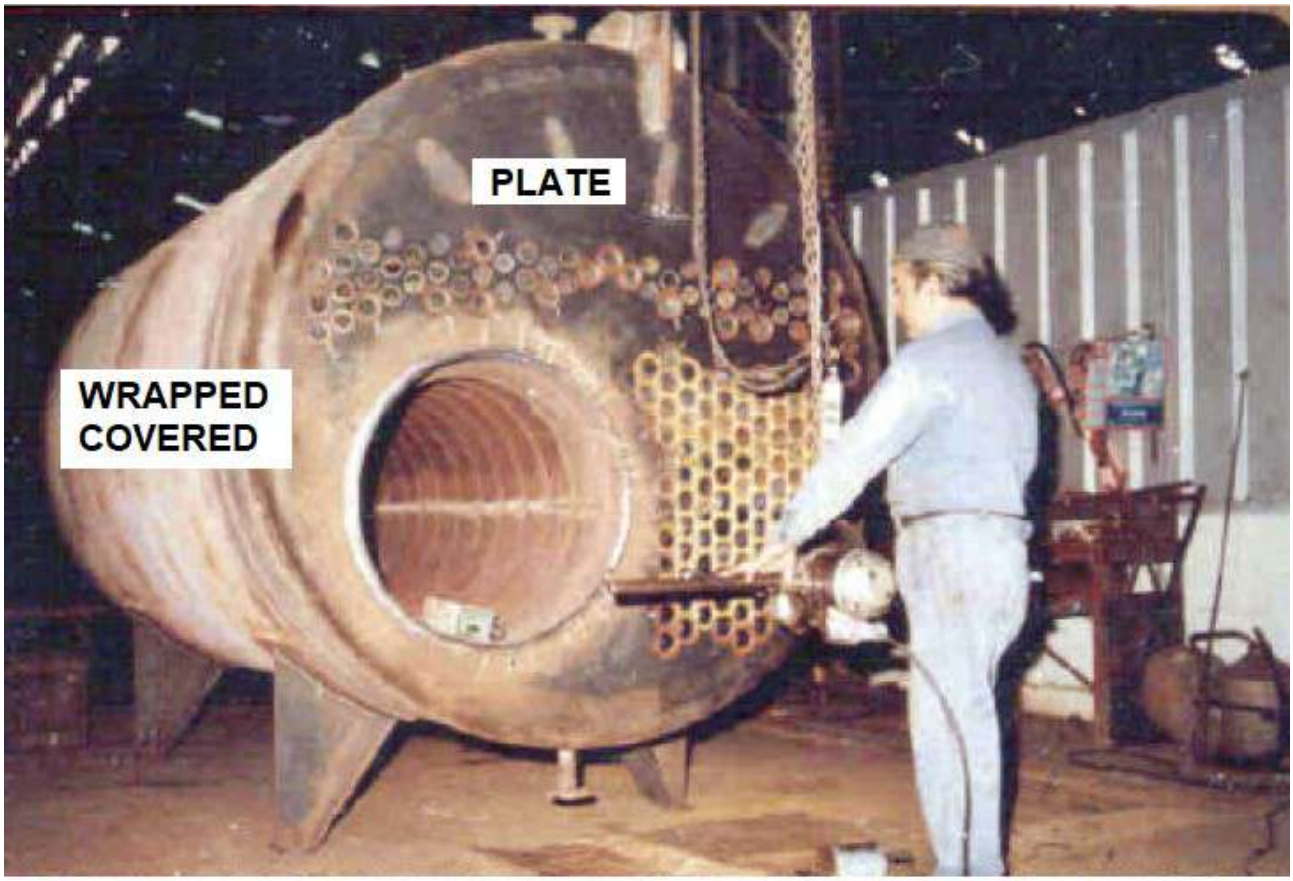
ESTADO DE LA CALDERA ANTES DE LIMPIAR

ESTADO DE LA CALDERA DESPUES DE LIMPIAR

URUMAN
Homenaje al
Ing. Nav. Carlos W. Thomasset
Profesor y Autor del Libro
"Pequeño Manual del Foguista"
por su contribución a la formación
de los foguistas del Uruguay.
Montevideo 17 noviembre 2022

URUMAN Conference, 17 noviembre 2022
(Uruguayan Society of Maintenance, Asset Management)
recognition to CWT for the authorship of the "Pequeño Manual del Foguista"
and ffor the training of boiler stokers in Uruguay (1980..2010).

CHAPTER 21: BOILER TUBE MANDRELLING



MANDRILLING BORING TUBES TO PLATES (HOMO-TUBULAR BOILERS)

Calculating the percentage reduction (flattening) of the tube over the plate hole based on the tube wall thickness (the tube must be the correct size for the plate hole).

Since a percentage reduction can be predicted according to the material being mandrel, that is, we can establish the final internal diameter of the tube after it has been mandrel to the plate.

Remember that excessive mandrelling or "flattening" is undesirable. It is preferable to have insufficient expansion and, if necessary, "adjust" without overdoing it.

An excessively mandrel tube can only be replaced or fitted with a smaller diameter support collar, which in some cases is not advisable, as it can cut off water flow in a water-tube system or cause it to burn in a fire-tube system.

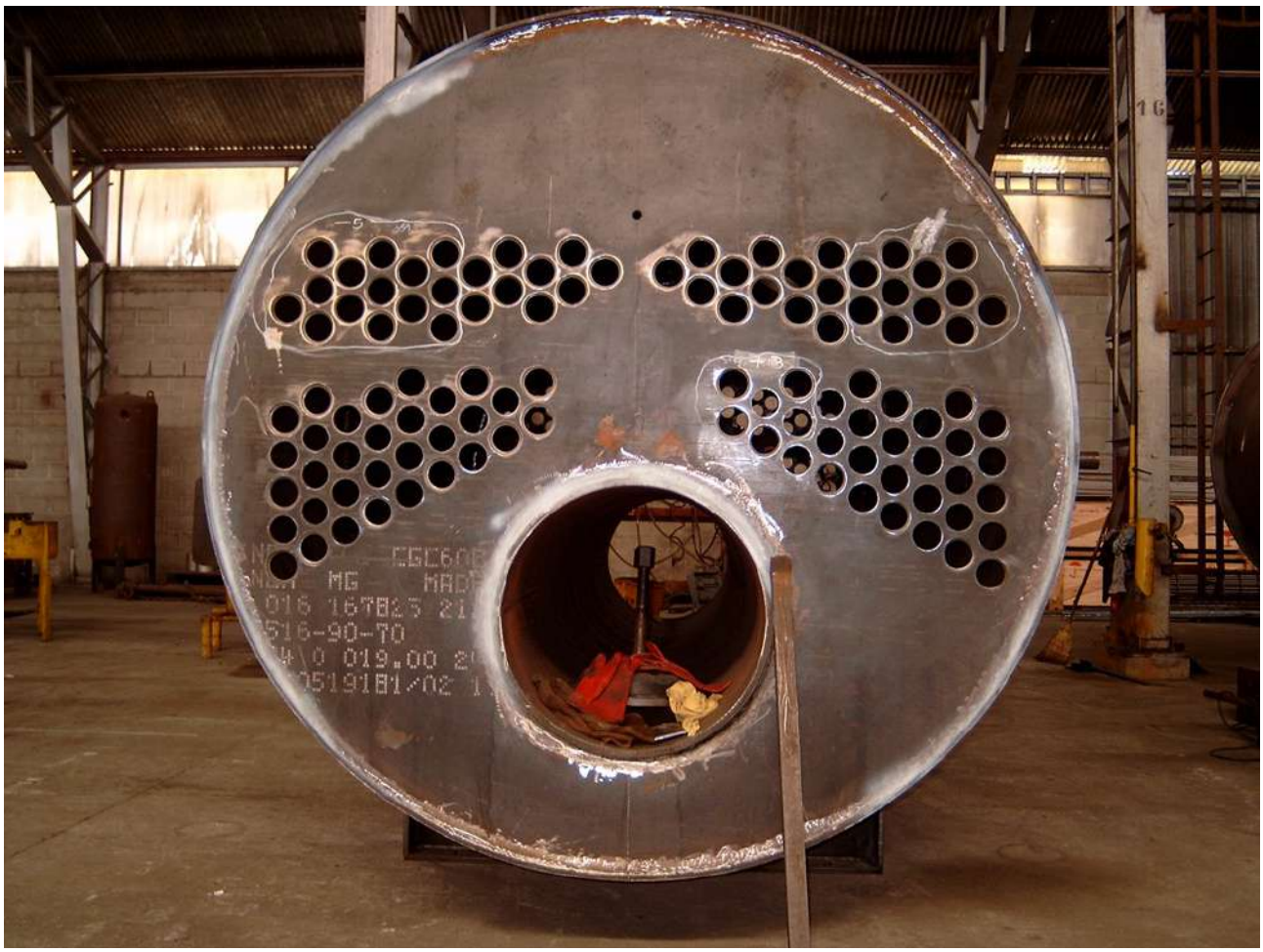
Admissible or recommended percentage reduction:

Copper and Copper-Nickel..... 8-10% reduction
Steel, Carbon Steel, and Admiralty Copper..... 7-8% reduction
Stainless Steel and Titanium..... 4-5% reduction

This percentage reduction means that when the tube is placed on the plate, both are prepared for mandrel boring: cleanliness, annealing of the tube (if necessary), and on the plate: a perfect and clean hole, etc.

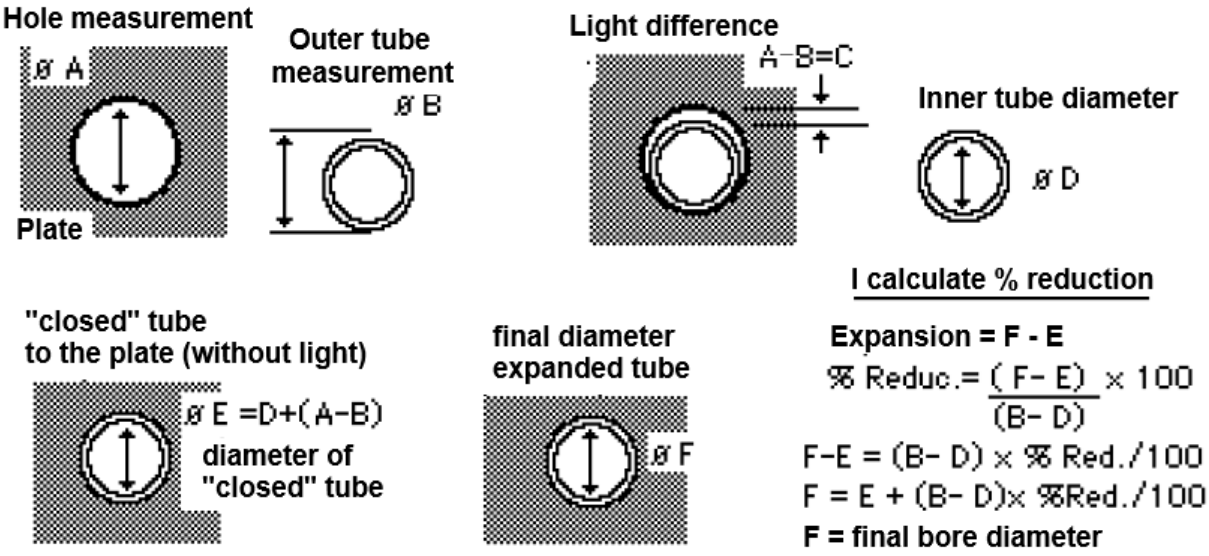
Then we must "bring" the tube to the plate with the mandrel until the light disappears (they "make contact").

From this moment on, any further movement of the mandrel will "compress" the tube against the plate (stiffening the tube), and the reduction of the tube in this last operation becomes the percentage reduction that we must respect, since an "excessively" mandrel-broken tube (a reduction percentage higher than recommended) instead of becoming firmer, will actually become weaker.



Each material will require the appropriate mandrel.

To calculate the final internal diameter measurement of the tube after mandrel, carefully follow the instructions below:



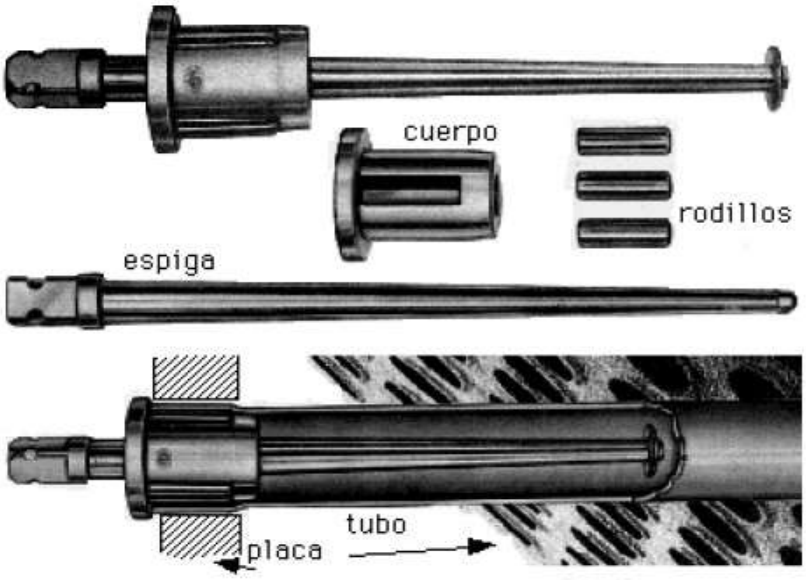
If there is a way to measure the "force" needed to reach that measurement on the "spindle" of the mandrel (measuring the "torque"), we perform it a few times until we can be sure that we can repeat the mandrelling with that maximum "force", we will be in a position to mandrel the following tubes guided by that limit (there is special equipment for this, with "torque" measurement or automatic preset "torque" limit, with electric motors or pneumatic motors).

It is important to keep the mandrels clean and lubricated with a high-pressure grease (generally molybdenum-based).

Pay attention to the tube's termination on the plate: whether it is flanged, flared, straight, flush, or welded, as the tube provides mechanical support for the plate. Flaring serves a dual purpose in some cases, both as support and as a guide for water circulation.

On the flue gas (flame/smoke) side, excessive extension or lack of flaring ("upset") in fire-tube boilers on the hotter side can be counterproductive due to the high temperatures that can burn the tube or allow it to loosen on the plate (as the mandrel section heats up due to excess surface area).

Furthermore, if the surface finish of the tube end is not properly completed, it will be the beginning of a future possibility of longitudinal cracking of the tube. Therefore, the finish must be smooth, without sharp edges, cracks, or other irregularities.



3-ROLLER TUBE EXPANDER (MANDRIL)

The hole in the plate must be polished and sufficiently round. If the deformation is not significant, it can be reshaped with a mandrel to achieve a rounded shape.

Three-roll mandrels work best where the plate holes are not perfectly round, while five-roll mandrels are recommended for perfectly round plates made of harder materials.

If you are inexperienced in tube mandrel, prepare a piece of iron sheet of the same thickness as the plate, drill several holes of the same size as the plate, and practice mandrel until you achieve the desired result and its appearance matches that of the boiler being mandrel.

It is advisable that a job of this scale be carried out by a company specializing in this field (with technical expertise).

There are other ways to control the amount of tube mandrelling on the plate, one of them being the use of a dial indicator, which is placed on the tube to be bored and its "point" rests on the plate.

MANDRILLING TUBES IN A WATER-TUBE BOILER DOME

The expansion is measured by the movement of the dial indicator as the tube "stretches" when it is held in place by the boring (after measuring the diametral deformation indicated at the beginning on the first tubes).

Today, in almost all fire-tube boilers, the tubes are mandrel-grooved and welded to the plate.

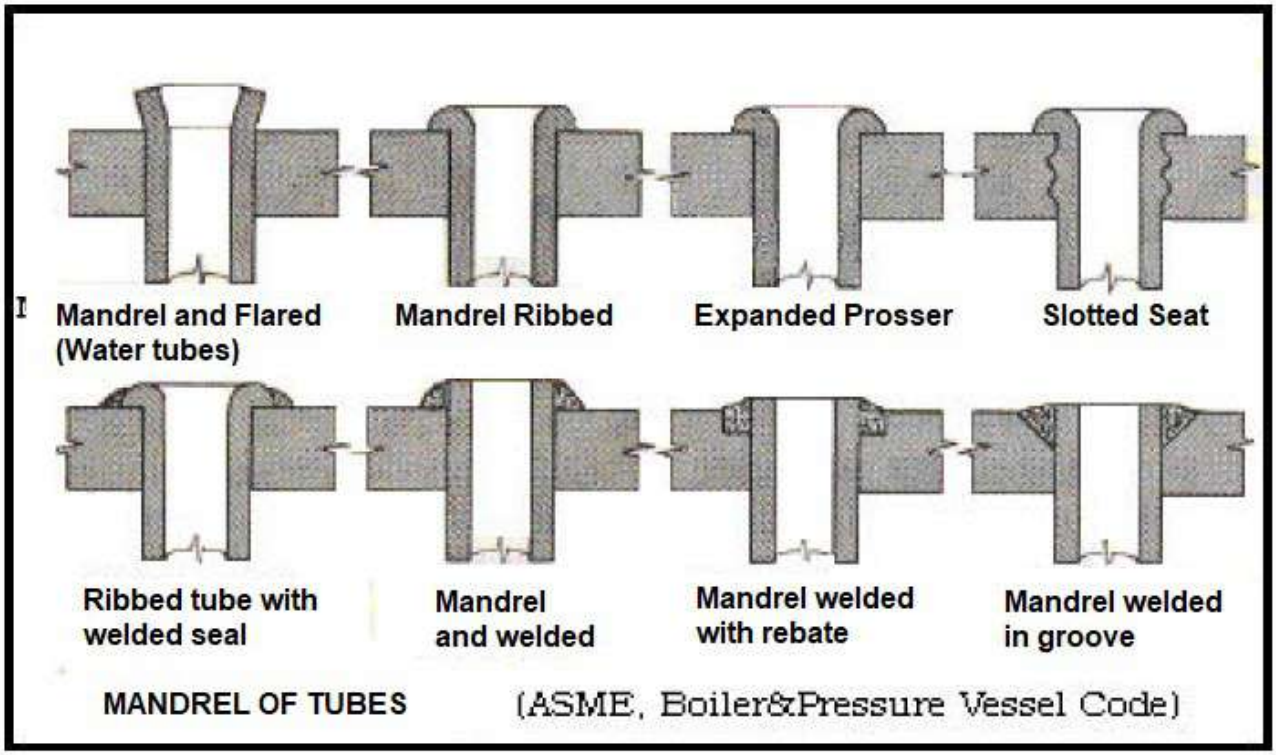
Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 21: TUBE MANDRELLING

The tubes are welded to achieve a good seal, but some tubes are welded deeper, as these are the "stay" or support tubes between the plates (meaning they withstand the pressure exerted on the flat plates).

Although the tubes will be welded, they must first be mandrel-grooved. After welding, they are mandrel-grooved again to loosen the tensions generated by the welding process and to retighten the mandrel that loosened during welding (the tube having reached a certain temperature).

Since the mandrel acts as an anchor for the tube to the plate, and the weld acts as a seal, and in the case of stay tubes, the weld also serves as an anchor,

if the tubes were not mandrel-grooved, problems would most likely arise over time, ranging from weld failures due to insufficient anchorage to corrosion in the gap between the plate and the tube.



These welds must be done very carefully and with the appropriate electrode (as otherwise the plate can be damaged or problems with cracks or corrosion can arise). It's important to remember that at the hottest gas inlet of the plate:

The gases, which generally enter after leaving the combustion chamber, have a temperature of almost 900°C (1652°F), causing a significant increase in the metal's temperature if it is not properly cooled by the water inside the boiler.

The tubes should not protrude beyond the plate into the gases by more than a specified amount, generally a maximum of 3 mm.

There should also be no overheated weld spatter or cracks in the tube or weld (as all of these will cause the material to suffer high-temperature corrosion, cracking the plate or tube,

or even loosening the tube on the plate, practically tearing off the sealing weld and negating the mandrel effect, due to the metal's plasticity at high temperatures). temperature.

Previously, with only mandrel-punched tubes, these tubes at the gas inlet were "flared," meaning the extension or end of the tube was neatly pressed onto the plate, so that no uncooled tube was exposed to the hot gases.

Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 21: TUBE MANDRELLING

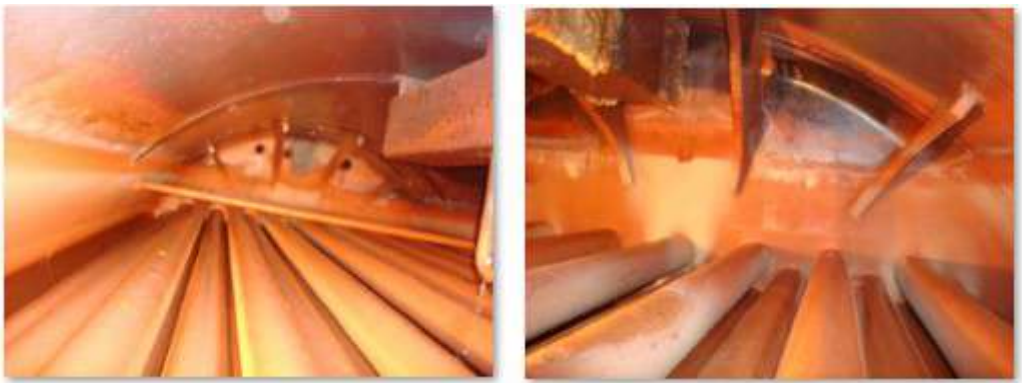
DIRECCION NACIONAL DE BOMBEROS URUGUAY
y
SERVICIO DE SANIDAD DE LAS FUERZAS ARMADAS
Agradecimiento a Carlos Thomasset por su permanante apoyo técnico
*** * ***
National Fire Department of Uruguay
and
Armed Forces Health Service
Thanks to Carlos Thomasset for his ongoing technical support

CHAPTER 22: REMOVAL OF BOILER TUBES FOR REPLACEMENT

When replacing tubes in fire-tube and water-tube boilers, one of the most delicate procedures is the extraction of the tubes mandrel-grooved and flanged to the plates or mandrel-grooved and welded to the plate.

This leads to various methods for cutting the tubes at the mandrels in order to remove the mandrel or welded tube sleeves without damaging the plate, since the tube seat on the plate hole must not be damaged under any circumstances.

This is because when the tubes are re-mandreld, this damage could cause a leak or the beginning of a crack in the plate.



FIRE TUBE BOILER: FRONT AND REAR PLATES AND TUBES

Remember that the tubes are not only mandreld or welded to maintain a watertight seal, but their function is also to support the internal pressure stress of the boiler on the plates.

The issue of expansion and contraction (which often exceeds the pressure stress) is also significant.

There are several methods for cutting the tube, then removing the tube sleeve that remains on the plate, and then making a longitudinal cut (to disassemble the mandrel tube sleeve and extract it), thus reducing its diameter by decreasing its expansion diameter.

The cut tubes are then extracted through a hand-operated cap on one of the plates. It could also be done without cutting the tube and instead making a longitudinal cut in the sleeve without separating it from the tube, then extracting it by applying force to one end, passing a sling or rod through the tube and pulling it with a heavy-duty jack (ratchet).

This method is very cumbersome because the tubes usually have some encrustation, which not only makes it difficult to pass through the hole in the plate, but can also damage the hole's seating surface due to the forced pulling of the tube.

When you see the methods that allow you to cut the pipe a few centimeters from the plate, it seems tempting to use a motorized internal pipe cutter (a tool that looks similar to a mandrel, but actually has an internal cutting tip that adjusts as you rotate the tool from the outside, as if it were a mandrel), usually motorized (air, electric, etc.) but there are also manual ones.

These methods seem tempting for cutting pipes, but they are very time-consuming, since the "cutting tool" must advance slowly to cut the pipe without expanding it.

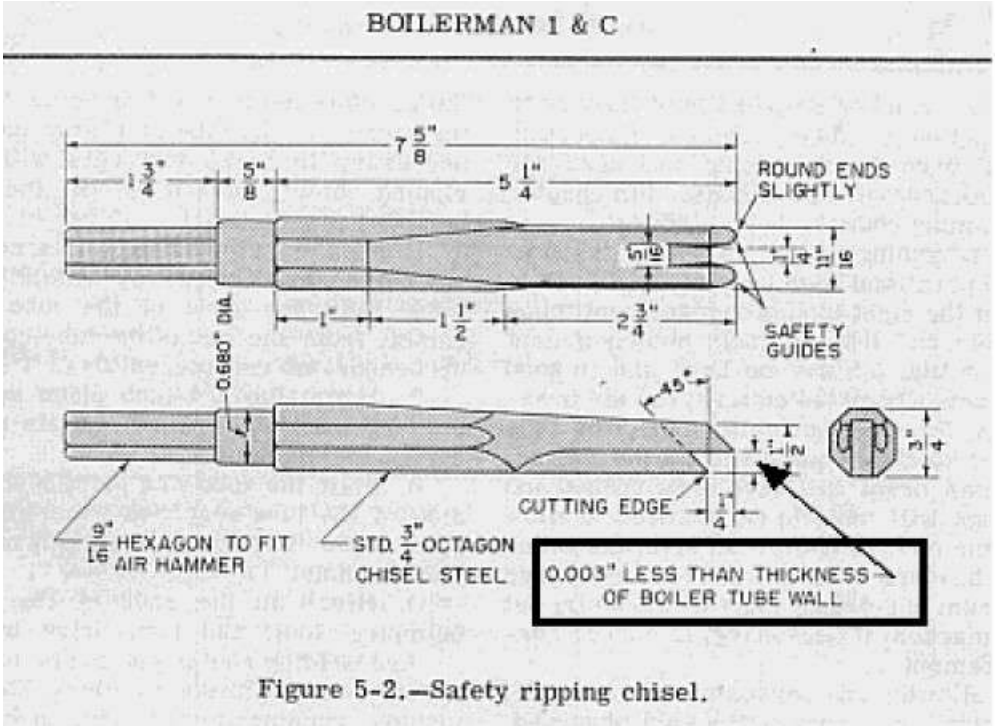
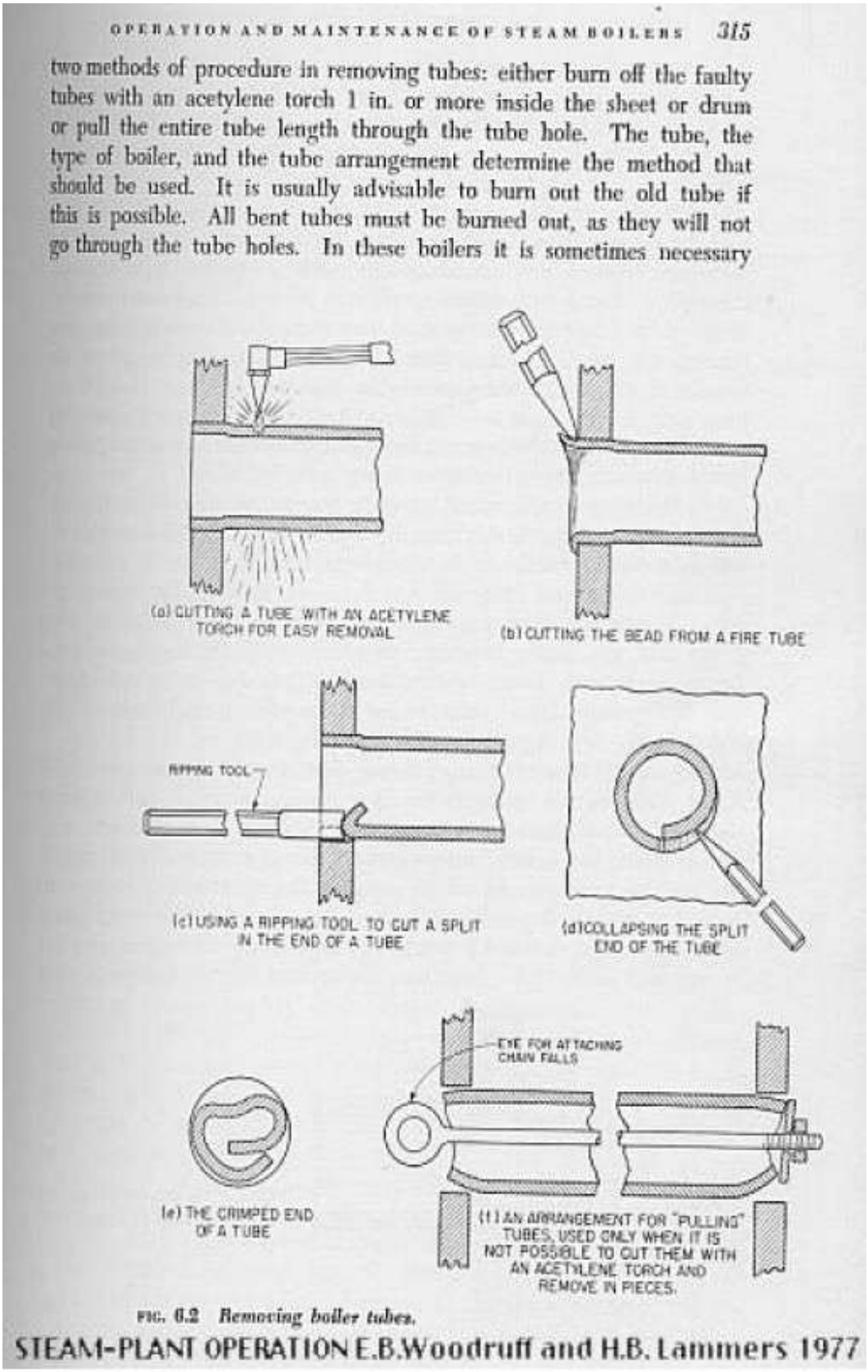


Figure 5-2.—Safety ripping chisel.

A well-trained torch operator can cut the pipes in a few minutes, and this operation does not damage the plate if done carefully, since the cut is made a few centimeters inside the pipe (usually 3 to 4 cm). Once the tubes are cut, they will exit through a cap in one of the plates, which is usually provided for this purpose.

The tube sleeve remains firmly attached to the plate; this is where the operation is most delicate, as the longitudinal cut of the sleeve must not damage the plate. A pneumatic or manual percussion tool can be used for this task.

Figure 5-2 (from the book BOILERMAN 1&C) shows the dimensions of one type of these tools.


OPERATION AND MAINTENANCE OF STEAM BOILERS 315
two methods of procedure in removing tubes: either burn off the faulty tubes with an acetylene torch 1 in. or more inside the sheet or drum or pull the entire tube length through the tube hole. The tube, the type of boiler, and the tube arrangement determine the method that should be used. It is usually advisable to burn out the old tube if this is possible. All bent tubes must be burned out, as they will not go through the tube holes. In these boilers it is sometimes necessary
(a) CUTTING A TUBE WITH AN ACETYLENE TORCH FOR EASY REMOVAL
(b) CUTTING THE BEAD FROM A FIRE TUBE
RIPPING TOOL
(c) USING A RIPPING TOOL TO CUT A SPLIT IN THE END OF A TUBE
(d) COLLAPSING THE SPLIT END OF THE TUBE
EYE FOR ATTACHING CHAIN FALLS
(e) THE CRIMPED END OF A TUBE
(f) AN ARRANGEMENT FOR "PULLING" TUBES, USED ONLY WHEN IT IS NOT POSSIBLE TO CUT THEM WITH AN ACETYLENE TORCH AND REMOVE IN PIECES.
FIG. 6.2 Removing boiler tubes.
STEAM-PLANT OPERATION E.B.Woodruff and H.B. Lammers 1977

The user should not assume that this eliminates the risk of scratching the pipe seat in the plate; it is a very dangerous operation if performed by a worker without the necessary knowledge and experience.

Producing a tool with sufficient hardness is not easy, since generally, the harder the tool, the more brittle it is, and the cutting tip tends to break.

Anyone who has retubed boilers with more than 200 mandrel tubes in the headers of sectional boilers knows that this method of longitudinal cutting (in relatively thick-walled tubes, e.g., 4.5 mm wall thickness), with the headers supported by the water and steam riser and downpipes themselves,

can lead to continuous "knocking" and loosening of the mandrel seats of the tubes that will not be replaced or that have already been replaced to hold the headers in place (including the seats on the upper and lower domes).

Although it may seem risky, I've seen torch operators making longitudinal cuts with a torch without damaging the plate seats (using bottled gas, not oxyacetylene).

MANUAL TUBE CUTTER

This is debatable, but often, in reality, it seems that the best isn't necessarily the best, and we have to accept realities that the books don't cover.

Now, if by using a torch operator who lacks the skill to cut the longitudinal sleeves quickly and without cutting to the depth required to mark the plates (or using an oxyacetylene torch), we're causing very costly damage to the plate seats.

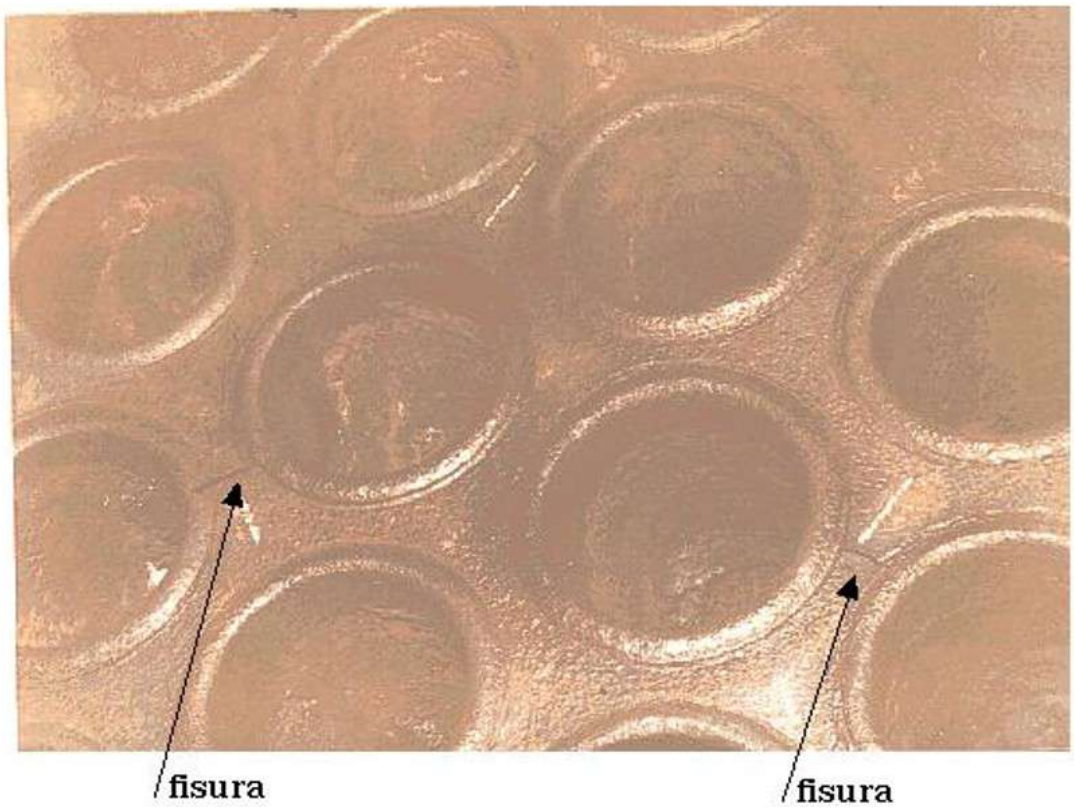
This method of using a torch for longitudinal cutting, based on cold logic, seems to show that the heat from the torch during cutting remains in the thinner sleeve (its temperature rises rapidly during the cut).

Since the much thicker plate remains cool (its heat dissipation is far greater than in the sleeve, therefore its temperature doesn't rise significantly).

Cutting with a gas cylinder flame temperature doesn't appear to damage the plate's seating surface (but be careful when using an oxyacetylene torch, where the cutting flame temperature is much higher, penetration into the sleeve can be excessive, potentially damaging the tubes' seating on the plate).

I've tried all the systems. I've seen plates damaged by improper torch cutting (when acetylene was used instead of propane and oxygen), but I've also racked my brains with longitudinal cutting chisels, as they aren't easy to manufacture and work with without breaking due to brittleness or denting due to lack of hardness.

Everyone will draw their own conclusions, but I recommend doing a preliminary test in the workshop, "practicing" before starting the work, with a piece of metal of similar thickness to the plate, with several mandrels (or mandrels and welds), and testing which method can be done safely.



Cracks in the plates of a tubular boiler can also occur due to other causes:

- Mechanical, thermal, and chemical effects.
- Scaling in the boiler.
- Boiler with excessive combustion.
- Very rapid starts.
- Internal foaming.
- Excessive pressure drops with the burner set to high.
- Use of fragile water.
- Excessive pH (very alkaline).
- Lack of purging.
- Excessive mandrel drilling. Very short combustion chambers.
- Boilers burning gas when they are not designed for it.
- Boilers with pronounced pressure variations.
- Boilers made with unsuitable metals.

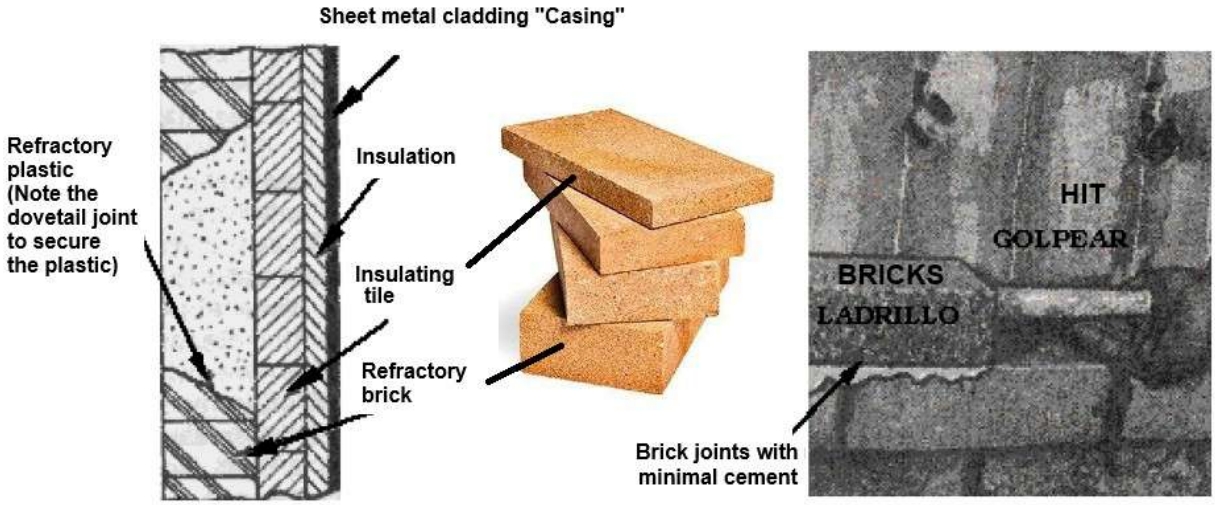
CHAPTER 23: REFRACTORIES

Boiler refractories must be repaired by individuals with refractory expertise ("fume fitters").

Expansion joints and the method of joining pieces must be carried out with expertise in the subject.

The materials to be used must be purchased and supplied according to the location and method of use (they vary with temperature, temperature variations, and the repair method).

All refractory materials that have been installed must be dried very slowly (except for refractory plastics for quick repairs) and over a low heat. Some refractories must be fired at high temperatures; others have already been fired in special kilns, as is the case with refractory bricks or other refractory pieces.



LEAVE EXPANSION JOINTS IN APPROPRIATE AREAS
THE INSULATION OF THE SHEET METAL (CASING) IS ESSENTIAL
THE "SPACE" BETWEEN BRICKS SHOULD BE AS SMALL AS POSSIBLE

When using "plastic" materials (refractories for quick repair), they must be perforated to allow steam to escape from the inside (otherwise, they will crack due to the internal pressure of the steam that forms).

When welding supports for the refractories (anchors), in very hot areas, they should be made of stainless steel (for high temperatures) and wrapped with a combustible material to allow for some play to absorb the metal's expansion; otherwise, they will stress the refractory material until it cracks.

Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 23: BOILER REFRACTORIES

Refractories themselves are not insulators; their function is to withstand the high temperatures generated during combustion (generally to protect the insulating material, which in turn protects the metal; they are very dense, meaning they are heavy).

Therefore, insulating materials must be placed between the metal and the refractory material (such as insulating brick, a very lightweight material; mineral wool, field brick, asbestos, vermiculite—the latter two are considered carcinogenic, and some vermiculites may contain asbestos fibers, etc.).

Areas that are exclusively enclosed by refractory material and that do not have water cooling (such as in water-tube boilers or tube "chapels", whether in liquid, gaseous or wood-fired boilers) must be insulated with some caution if the temperature is high or if it is in contact with combustion, since an excess of insulation does not allow the temperature "gradient" necessary to prevent the refractory mass from reaching the same temperature as the combustion, which causes deterioration of the refractory and sometimes deformation of the anchoring system.

Refractories in boilers (whose combustion tends to be acidic) are generally made of acidic materials (such as silica and aluminum in combination with other elements).

Alkaline refractories (generally based on magnesium or calcium) are also used, typically in some types of furnaces (which mix fuels with alkaline elements, such as lime kilns).

All of this means that we must respect the use of acidic refractories with acidic combustion characteristics. Otherwise, if we were to use a refractory material that is different from the characteristics of the environment, a reaction would occur that causes the refractory to deteriorate (acids combine with alkaline elements and cause deterioration).

There are materials better suited for emergency repairs, which cannot be left to set for a while, such as "plastic" refractory clay (this material is kneaded, with almost no water, like putty, so that it can be formed into a ball without cracking).

This material should be applied to areas that have been previously prepared so that it creates its own anchor (like a dovetail joint or what a dentist does to place amalgam). When applying the material, it is tapped with a mallet ("tapped").

Then, small holes are made with a thin steel wire (to allow the steam that forms inside when heated without drying to escape). This material can be heated gently immediately until cooked.

Concretes (of the concrete type) must be poured as if they were regular concrete and require a setting and drying time, followed by a very slow firing of several hours to reach working temperature.

If a metal frame is placed inside, it must be covered with a material that will burn (paper tape wrapped around the iron, tar, or another material that forms a layer). This thickness, as it disappears, allows the metal to expand without breaking the refractory material.

To create "screens" or protect the pipes from direct fire, special refractory materials (such as chrome-ore) are used. These are placed over the pipes, which have "pins" or "docks" (sometimes made of stainless steel) to which the refractory material is anchored.

Expansion must be carefully considered to prevent the refractory material from cracking due to excessive pressure.

The expansion grooves (formed with combustible materials such as cardboard, wood, synthetic foam, etc.) must be sealed with a bead of asbestos (a type of asbestos that is more silky, now banned and replaced by materials with similar mechanical and thermal resistance, such as mineral wool) after the materials have burned.

This prevents small fragments of the refractory material from entering the groove, which, once filled, would reduce its capacity to allow for expansion.

EXPANSION TO CONSIDER FOR EACH REFRACTORY MATERIAL	Thermal Expansion 0-1400°C	Inches per Foot
95% Silica Bricks	1.25%	5/32
Firebricks	0.75%	3/32
High Alumina (50-60% Al_2O_3)	**0.8%**	**3/32**
High Alumina (over 60% Al_2O_3)	**0.9%**	**1/8**
Magnesite Bricks	1.74%	1/4
Chrome-Magnesite Bricks	1.38%	3/16
Unburned Magnesite Bricks	1.5%	3/16
Unburned Chrome-Magnesite Bricks	1.2%	5/32
Chrome Bricks	1.16%	5/32

Cold drafts should be avoided on refractory materials, as they cause cracking.

The more "high-temperature rated" the refractory material is, the more care must be taken to protect it from cold drafts.

These cold drafts cause cracks in these very hard and high-density materials. Therefore, softer materials, i.e., those with a lower silica or alumina content, should be placed over the loading openings.

When installing refractory bricks or pieces, **while expansion gaps must be left, the bond between them is achieved with a very thin cement base** (this differs from a common brick wall, where the assembly relies on interlocking the pieces rather than filling the joints, since too much cement tends to loosen and cause the wall or arch to collapse).

The arches must be constructed with the appropriate pieces ("blades") at the necessary angles to close the arch with minimal use of cement. This is crucial, as the arch will move due to the expansion and contraction caused by varying combustion or cooling temperatures.

A boiler or furnace with a large amount of refractory material should be cooled slowly and not by force using forced air, as this would be very detrimental to the refractory material.

Another problem to consider with refractory materials is their high weight (their high density or weight per unit volume: kg/dm^3).

This means the support base must be adequate to bear this weight, especially considering that corrosion or deterioration of the metal structures will occur over time.

Hot refractory materials should not be wetted with cold water. Hot water can be used if necessary, provided the refractory temperature is already relatively low.

Therefore, if installing a combustion suppression system, ideally a steam injection system should be used, not water (but if water must be used, it should be a mist, not a jet).

Refractory material is often used to protect exposed parts of the boiler from excessive heat. Otherwise, these parts would not only "burn" from the direct radiant flame, but excessive heat transfer would also cause poor internal water circulation, leading to problems in that area or elsewhere.

Examples of elements protected from excessive heat:

a- Horizontal collectors: Two factors necessitate insulation here: the thickness of the metal, which hinders cooling, and the horizontal position, which impedes the evacuation of any steam that may form. Internal circulation can be affected because the mass of water is displaced to a much larger volume, reducing water circulation.

b- Some parts, such as gas generators, whose internal circulation can be inherently difficult if steam forms (remember that 1 kg of water at 10 kg/cm² occupies a volume 180 times greater when it vaporizes, which reduces the circulation of the internal water mass, preventing sufficient cooling of the gas generator, both tube and jacketed types);

c- Areas exposed to very intense radiation (such as screen tubes or baffles);

d- Domes and collectors exposed to radiant areas (given the thickness of the metal and its poor conductivity, proper cooling is not possible).

'PERCENTAGE CHEMICAL COMPOSITION OF REFRACTORY BRICKS
(M.R. Villanueva)

Brick Class	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Cr_2O_3	Oxides Secondary
Primary Silica	94 a 97	1 a 2	0,5 a 1,5	2 a 3,5	—	—	1,5 a 2,5
Secondary Silica	92 » 94	1 » 5	0,5 » 1,5	2 » 4	—	—	1,5 » 2,5
Refractory Clay (1)	50 » 65	32 » 45	0,8 » 3	0 » 0,5	0,2 a 0,5	—	3 » 6
Semi-acidic Chamotte	65 » 85	12 » 32	0,8 » 3	0 » 0,5	0,2 » 0,5	—	4 » 7
Magnesite	2 » 6	1 » 2	4 » 8	1 » 2	83 » 89	—	5 » 10
Chromite	3 » 6	15 » 33	—	—	14 » 18	30 a 45	—
Regulatory for the Navy (2)	40 » 58	40 » 46	1,8	0,5	0,3	—	—

(1) Basic Chamonite
(2) Alumina and clay. They also contain, at most: titanium 2%; alkali 0.7%. Melting point: above 1720 °C. They are used for oil furnaces."

Refractory material is also used to raise the temperature of the firebox in certain areas, improving combustion (since it is a poor conductor of heat, provides protection, and has high density, accumulating and reflecting heat).

This applies both to the burner area (serving a dual function: protecting and stabilizing the flame through radiant heat from the burner itself) and to the combustion end zones, preventing excessive flame cooling, which would extinguish the flame below a certain temperature (producing soot, unburned gases, etc.).

Boiler Repairs:

When we talk about repairs, we might think of something simpler than building a boiler, but this isn't the case:
A repair of the casing, plate, or firebox is a much more serious undertaking.

These repairs must be carried out by authorized workshops, with subsequent inspections (visual inspection, X-rays, ultrasound, etc.).

Hydraulic testing must be performed by an experienced technician. The repair must be reported to the Ministry (LATU) along with the corresponding inspection report.

Tubes can be removed, provided that their percentage does not affect circulation, create gas passages, or reduce the boiler's capacity.

Tubes can be removed with plugs (in some cases, provided there is no problem with overheating of the plate and plug) or with dummy tubes (a closed section of tube, mandrel-bored in place of the burned-out tube).

In some cases, refractory material must be used to seal the plugs or passages left by the burned-out tube.

Names of associations involved in boiler construction and operating standards.

In our country, the Eastern Republic of Uruguay, there are standards and regulations established by the Ministry of Industry and Energy, the Ministry of Labor and Social Security, the State Insurance Bank, some Departmental Governments, the Fire Department, UTE (the state-owned electricity company), UNIT (the Uruguayan Institute of Technical Standards), LATU (the Technological Laboratory of Uruguay), etc.

These standards and regulations do not cover all those necessary for boiler manufacturing, including references to materials, construction conditions, treatments, and quality controls. Therefore, when requesting the construction or repair of a boiler, we must ask which standards (and organizations) govern the aforementioned items.

These associations or standards names are:

American Standards:

ASME - American Society of Mechanical Engineers. ASME Boiler and Pressure Vessel Committee (Section of the previous society that deals with boilers and pressure vessels).

ABMA - American Boiler Manufacturers Association. Which accepts the standards of the previous society.

ASTM - American Society for Testing and Materials.

AGA - American Gas Association.

ANSI - American National Standards Institute, Inc.

NEMA - National Electrical Manufacturers Association.

NFPA - National Fire Protection Association.

UL - Underwriters Laboratories, Inc. AWG - American Wire Gauge.

SBI - Steel Boiler Institute.

NEMA - National Electrical Manufacturers Association.

AWS - American Welding Society, Inc.

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASA - American Standards Association, etc.

Argentine Standards: IRAM.

European Standards:

NBN - Belgian Standards.

VDTUV - German Standards.

BRITISH - English Standards.

ABG-28 - Danish Standards.

CECT - European Recommendations.

Other standards that may be considered:

TDR - Technical Rules for Steam Boilers

DIN - German Industrial Standards, etc.

ISO - International Organization for Standardization.

BS - British Standards.

SAE - Society of Automotive Engineers

AISI-American Iron And Steel Association

AWWA-American Water Works Association.

NEWWA-New England Water Works Association, Etc.

BOILER EXPLOSION DUE TO LOW WATER LEVEL

CHAPTER 24: BUYING A BOILER

When buying a boiler we must take into account:

1- The fuel (or fuels and their quality under the worst conditions).

Not all types of boilers can burn every type of fuel.
We can establish that if the boilers are specifically designed for their respective fuels, the following approximate ratios apply:

1 Lt of heavy fuel oil is equivalent to 3.0-3.5 kg of firewood with 25% moisture content.

1 Lt of heavy fuel oil is equivalent to 1.05-1.15 m³ of **natural gas** (Paysandú Uruguay natural gas).

1 Lt of heavy fuel oil is equivalent to 3.3-3.6 kg of **rice husks** with 10% moisture content.

These values are affected if the boilers have heat recovery systems, which is not always possible (due to corrosion problems).

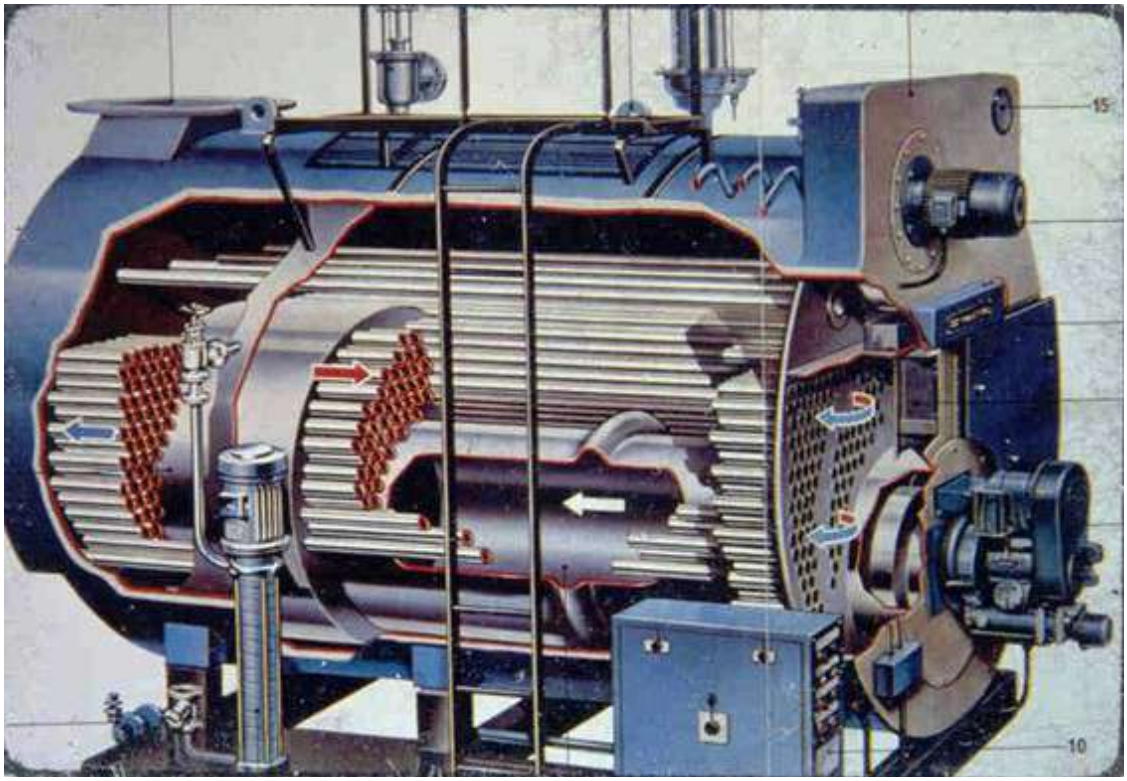
When a boiler is intended to burn natural gas, it's essential to consider whether the design is suitable for natural gas combustion. Otherwise, there's a risk of loosening tubes and cracks in the hottest plate, since gas has a higher temperature at the end of the combustion chamber due to its different heat transfer compared to liquid fuels.

The latter have a more radiant flame, located closer to the burner, which cools the flame rapidly in the combustion chamber before it reaches the hottest plate.

Furthermore, when burning natural gas, a fuel that is very difficult to store and subject to supply interruptions, it's advisable to have alternative fuels available (such as a dual-fuel burner that can burn either liquid fuel or natural gas).

2- The quality of the makeup water and condensate, and the possibility of treatment (chemical and mechanical cleaning).

Some boilers cannot tolerate process contaminants (oils, grease, etc.), others cannot tolerate sludge or are sensitive to any kind of scale buildup, and still others are prone to accumulating contaminants, etc. Not all types, and even within those types, not all models have mechanical access for cleaning.



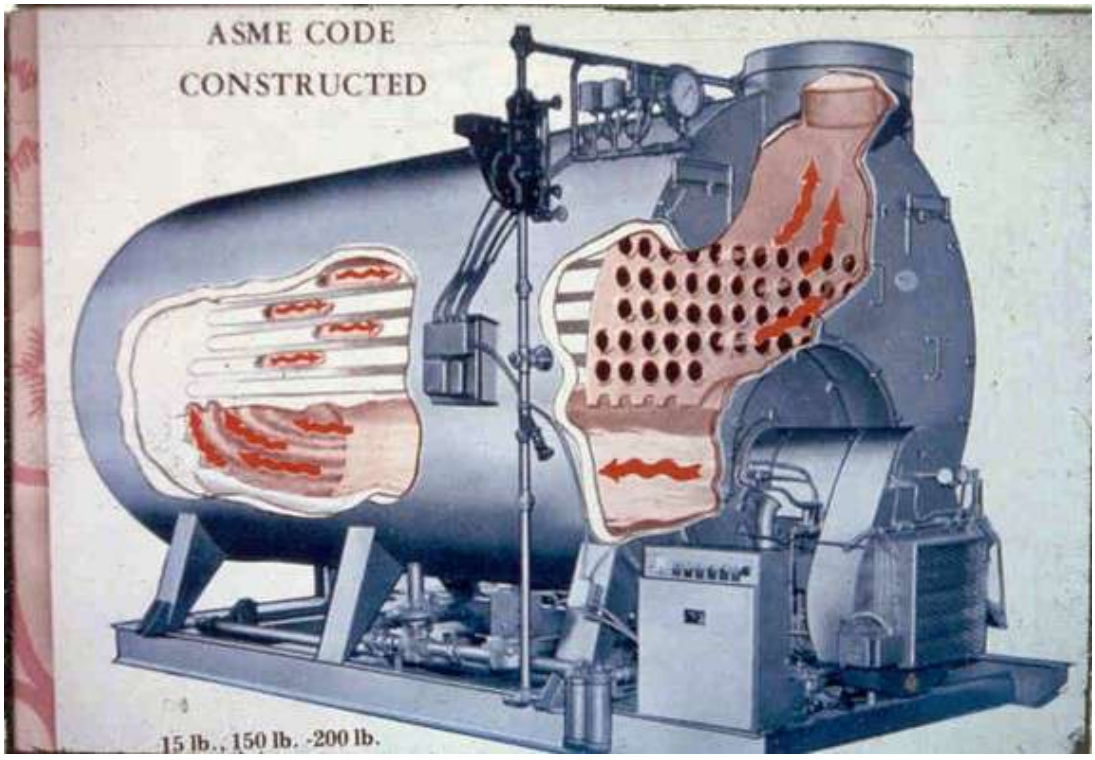
3- Normal operating pressure and its limitations (response).

Some boilers are slow to respond to pressure changes, which affects their performance or steam quality.

4- Temperature (saturated or superheated steam) and steam quality ("quality," "title," or moisture and purity).

Depending on its use, the temperature and quality of the steam are key.

A boiler may not function correctly for supplying steam to a turbine (due to entrainment and the need for superheating), or the desired steam purity may affect the process (dyeing, food processing, etc.).



5- Hourly Steam Capacity (kg/hour) and Overload Potential (%).

This capacity must be calculated based on the plant's maximum steam requirements, considering a "peak" or overload percentage for plant startup or for anticipated future increases in steam consumption.

When expressing boiler capacity, care must be taken, as it varies according to steam pressure and feedwater temperature.

One way to avoid this confusion is to express the **steam capacity in kg/hour of steam at 100°C / 212°F** (evaporation equivalent), or alternatively, to express the parameters mentioned above: pressure, steam temperature, steam quality, and feedwater temperature (both expressions are interchangeable).

We must consider that the appropriate capacity at which the boiler will be used should not only be the point of maximum efficiency, but also ensure adequate steam quality.

Generally, around 70% is ideal, since when the boiler operates above 70%, steam quality problems arise: carryover and foaming, related to established chemical limits. This is because specific vaporization is currently very high, which means a greater degree of internal instability.

The hourly steam capacity in kg can also be established in relation to the hourly fuel consumption. Therefore, we can establish the following approximate relationships for a saturated steam boiler with a pressure between 7 and 10 kg/cm²:

1 Lt of heavy fuel oil.....12.5 to 14.5 kg of steam

1 kg of 25Hbh firewood.....3.8 to 4.8 kg of steam

1 kg of 10%Hbh rice husks.....3.6 to 4.2 kg of steam

1 m³ of natural gas (Pay) .....12.5 to 13.5 kg of steam

These values are related to the boiler design, operating percentage, heat recovery units in the flue, excess air, combustion quality, feedwater temperature, saturated steam, superheated steam, insulation, losses and blowdown, etc.

6- Overall Efficiency relative to the LHV (%) at 100% capacity.

This allows us to get an idea of the kg of steam per kg of fuel to compare different offers. (The fuels and other parameters must be the same for the comparison to be valid).

Here, the overall efficiency of the boiler will be indicated (Combustion and Transfer Efficiency, Boiler Efficiency as a thermal equipment: insulation only, since it is assumed that the blowdown valves will be closed during the test and there should be no water or steam leaks).

This Overall Efficiency relative to the LHV at 100% capacity is currently around 90% at the LHV. (since the Thermal Efficiency in general is between 97% and 99%, and the Combustion and Transfer Efficiency is between 88% and 91% at the LHV, both depending on the type of boiler related to the type of fuel and its heat recovery systems.

Remember that 100% capacity is not the point of maximum efficiency (it is generally close to 70%).

It's important to note that when we refer to Efficiency based on the Lower Heat Load (LHV), the percentage provided is more representative of the boiler's performance, while Efficiency based on the Lower Heat Load (LHV) provides a percentage that better reflects the fuel's behavior.

Americans (USA) generally use LHV Efficiency, while in Europe (and typically in Uruguay), LHV Efficiency is used.

The key point here is to be very careful when comparing offers (economic proposals for buying or selling new or used boilers) with efficiencies expressed in different units.

Generally, LHV Efficiency is a few percentage points lower than LHV Efficiency, and the greater the difference between the fuel and LHV, the lower the percentage difference. and the PCI, this difference will be greater, although although the % in numbers are different, they indicate the same thing, since each % of Efficiency expression must be multiplied by the respective PCI and both will give the same amount of heat used.

7-Combustion Efficiency (LHV) over time.

Cleaning periods without a noticeable loss of efficiency are generally observed as an increase in flue gas temperature, thus increasing the heat loss.

This allows for advance planning of downtime for cleaning (which has a cost) and whether fuel consumption will increase excessively between periods due to efficiency loss from boiler fouling.

The flue temperature is most affected by fouling of the heat transfer surfaces, and therefore combustion and heat transfer efficiency decreases between cleaning periods.

8-Safety System:

Safety valves (2 minimum recommended), level controls (2 minimum with combustion cutoff), level control valves, pressure switches, alarms, fusible plug (if required by regulations), etc.

Verify that the safety valves are indeed fully open, have differential pressure, and include a test lever.

9-Purge Blowdown System:

-Level purges blowdowns (connected for full opening),
-Bottom blowdowns (preferably a double valve with a quick-acting one),
-Continuous (surface) blowdown.

10-Inspection and Cleaning Access Points:

Manhole if necessary, head and hand access (near the blowdowns, feed inlets, bottom sections, and top section for monitoring chemical and mechanical cleaning).

11- Feed pump with sufficient capacity for extended service (pressure and capacity), taking into account the water's chemical conditions and temperature (packing or mechanical seal), intermittent or continuous service (continuous regulation), efficiency (or power consumption).

Alternative feed system: steam injectors or alternative pumps (cellulosic combustion boilers: wood, husks, etc.)

12- Combustion control: systems related to its safety, continuous modulation (best efficiency is achieved), semi-modulated (by steps), or intermittent (on-off) with the lowest efficiency.

13- Construction and testing standards: ASME, NBN, VDTUV, IRAM, CECT, etc.

14- Warranty, inspections during and at the end of the warranty period.

With direct and indirect efficiency measurements.

Within the manufacturing controls: it is important to ensure compliance with construction inspections, especially radiographs of welds in areas specified by the standards (envelopes and domes, etc.), stress relief according to standards, which is done by annealing (normalizing) of pressure-bearing parts (generally enclosed with their plates, furnaces and domes, etc.), the specified hydraulic tests, etc.

Before buying a boiler, it is advisable to: ask the manufacturer for locations where similar equipment is installed, visit these establishments in person, and speak not only with the managers but also with the boiler operators in charge of the boilers (without the boiler manufacturer present, as a follow-up visit can be arranged later, during which you will be prepared to ask questions).

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On the first visit to the supplier of the new (or used) boiler, it is advisable to ask about:

Compliance with the boiler specification and NAMEPLATE.
Response to changes in consumption.
Warm-up time for commissioning.
Periods between cleanings and
flue gas temperature variations during those periods.
Problems with steam quality.
Loosening of tubes.
Furnace explosions.
Response to different fuel qualities.
Ease of cleaning the flue and water sections.
Steam output (kg of steam per kg of fuel,
if wood, ask about moisture content).
Number of personnel required for operation.
Limits on fuel quality (moisture content for wood).
Limits on feedwater quality (entrainment problems or foaming).
Areas of poor water circulation (likely sludge deposits).
Heat recovery systems (efficiency and cleanliness).
Ease of operation, etc.

One of the most important limitations in boiler combustion is the maximum amount of heat per cubic meter (kcal/m³) that can be released in the combustion chamber (average in kcal/m³), as well as the maximum peak heat flow per surface area (kcal/m²).

It is crucial to ensure that the manufacturer complies with this standard, as it is closely linked to the safety of cylindrical combustion chambers, in particular.

For example, in fire-tube boilers, the limit is 1,250,000 kcal/m³ according to the British Engine Regulations, and the peak heat flow limit per surface area of the combustion chamber is 250,000 kcal/m² according to ABG 28, etc.

This limit affects even the thickness of the cylindrical combustion chamber material. In water-tube boilers, this limit affects the water circulation within the tubes, which can potentially overheat and burn due to insufficient cooling.

The cylindrical combustion chamber of fire-tube boilers can be "corrugated" (with cylindrical shapes of varying dimensions and profiles, which allows the chamber to better withstand pressure and partially absorb the significant

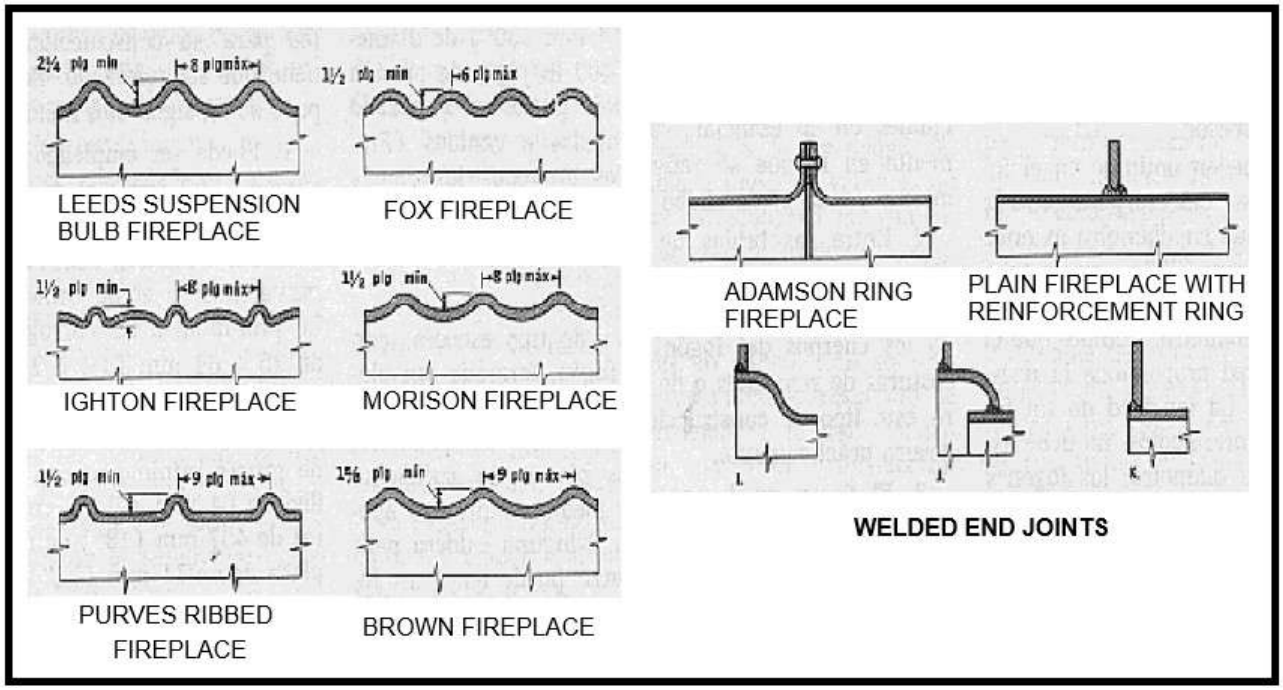
expansion stress caused by the high temperature of the flame inside).

Or "smooth" (a simple cylinder, which may have cylindrical supports, such as rings, on the water side, i.e., the cooled side; smooth cylindrical combustion chambers are limited to small-capacity boilers, since the problem of expansion is not taken into account, although in some cases a single "ruffle" or "expansion joint" is added for this purpose).

The most common "corrugated" system is the FOX system (since it is the simplest to manufacture).

Typically, once the firebox has been rolled with a single longitudinal weld, being rolled from a single sheet, it is placed on a type of lathe with embossing wheels shaped to create the "crisp" and torches that heat the material in the area to be deformed.

Another way to make a "corrugated" firebox is to create it in two halves using a press, after preheating the material to be deformed, and then welding the two halves together.



Different types of cylindrical smoke-tubular fireplaces

The expansion of the cylindrical combustion chamber in a fire-tube boiler causes stress between the plates (unless the combustion chamber is "floating," as in some return-flame boilers).

The tubes connecting the plates and the casing bear this stress, since the heating of the combustion chamber at certain times causes greater expansion than the tube passages.

Therefore, there are reinforced tubes, "stays," whose function is to withstand this significant stress and the pressure exerted by the boiler itself, which acts on the plates.

These plates are flat, and therefore their shape is not ideally suited to withstand stress that could distort them.

Today, tubes are mandrel-grooved and welded. Previously, in the 1900s, they were only mandrel-grooved and upset (that is, their ends were flattened or flared for two reasons: to better withstand stress and to prevent the protruding ends of the tubes from burning during the first pass, where the temperature reaches 900°C at the furnace outlet).

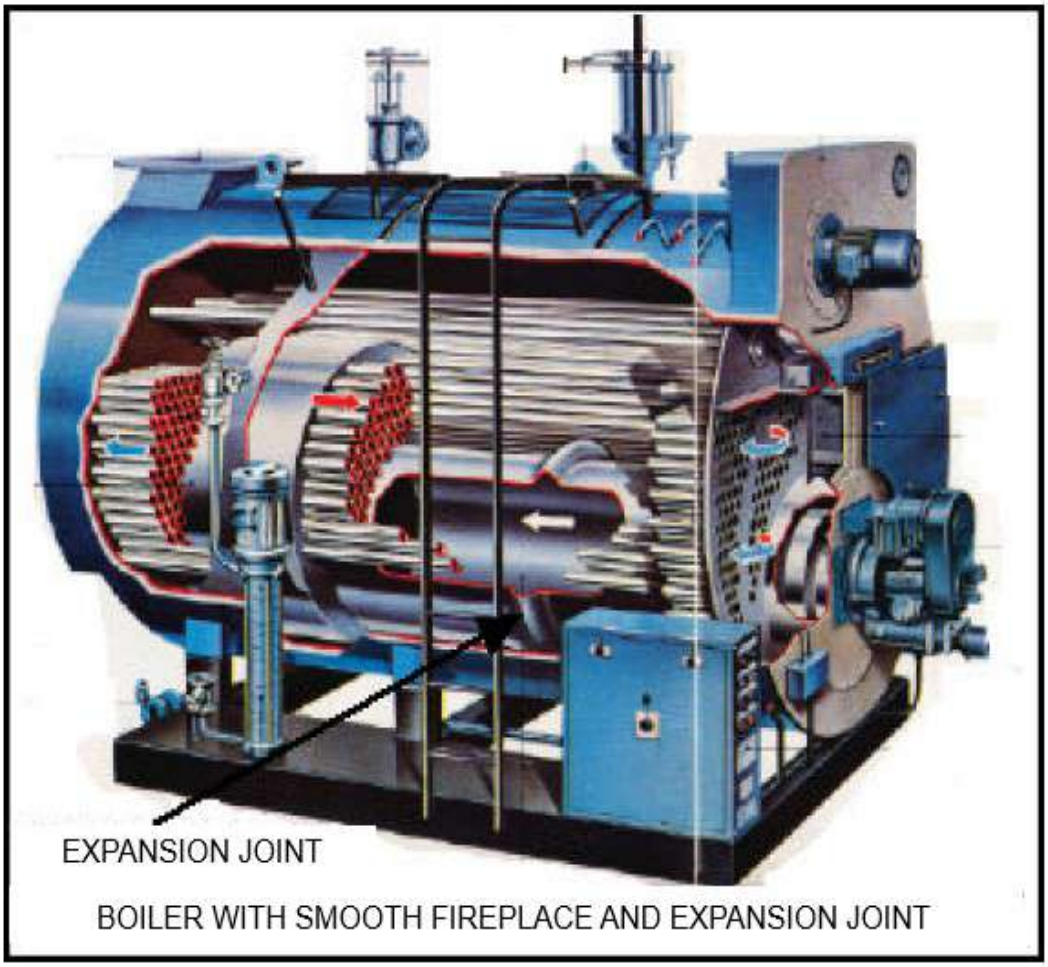
Stay tubes used to be thicker, sometimes with securing nuts. Today, these tubes are generally welded with a stronger weld, a deeper weld, than tubes that only need to maintain a watertight seal through welding.

When a boiler is scaled, the combustion chambers, plates, and tubes experience less cooling, leading to increased expansion that tends to crack the mandrel welds, loosen the mandrel tubes, crack the tubes and plates between tube holes, or even cause cracking at the combustion chamber ends, or, in some cases, fatigue and collapse.

This same problem of abnormal expansion occurs when boilers are heated too quickly from a cold state.

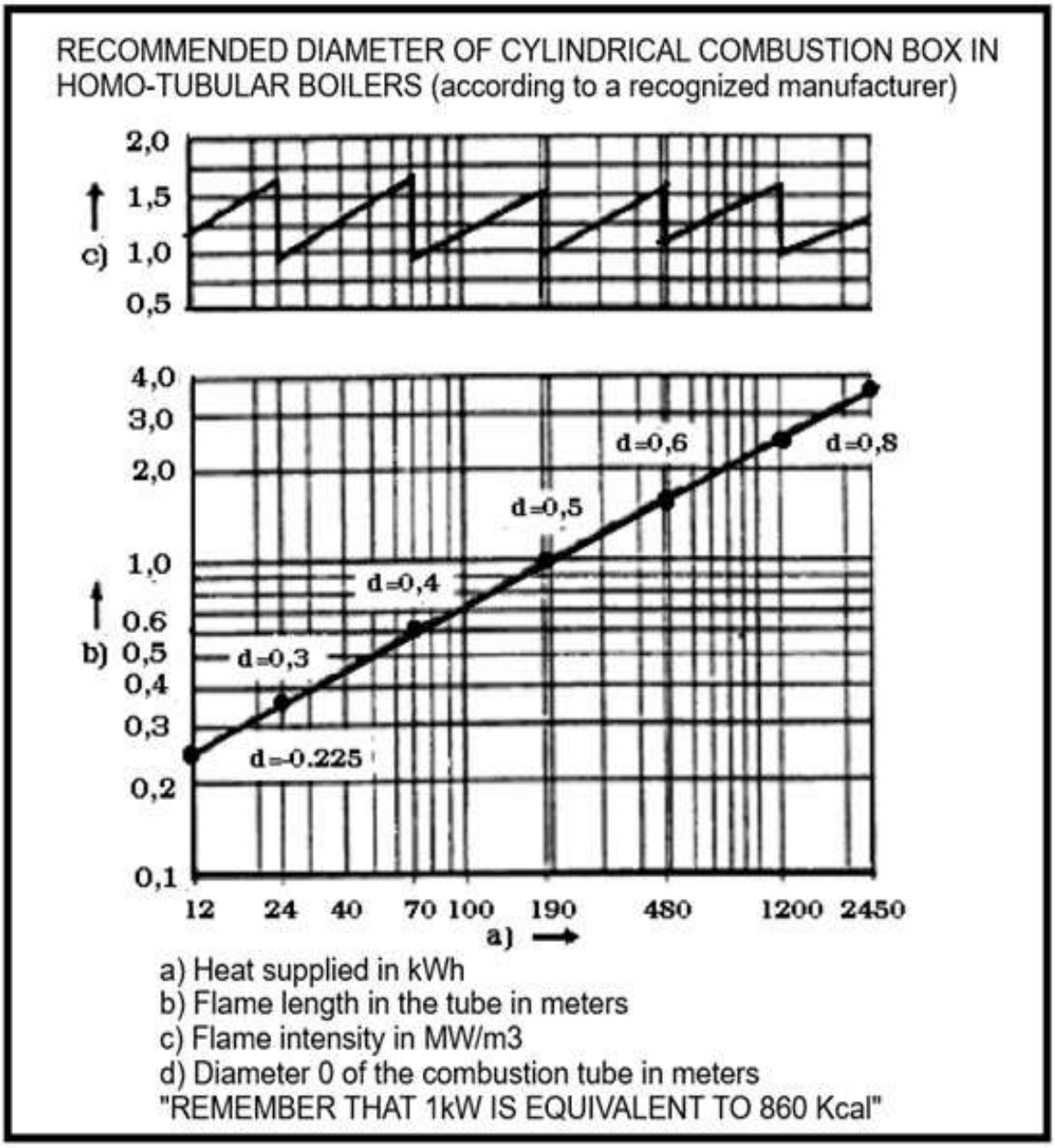
The same thing happens when the chemical conditions of the water do not allow for proper cooling of the transfer surfaces, due to alteration of the internal circulation (high TSD, high pH, alkalinity, etc., or contamination with elements that alter the surface activity of the water.

All these problems are observed when there is "agitation at visual levels" above normal, and the solution is generally to open the "continuous purge blowdown" to the maximum until this situation passes; it is also advisable to lower the boiler's vaporization until this moment of agitation passes).



BOILER WITH SMOOTH FIREPLACE AND EXPANSION JOINT

But whatever the type of cylindrical hearth, there is a **minimum diameter for each maximum combustion power of the boiler.**



The diameter of the combustion chamber in a fire-tube boiler plays a very important role, especially in the combustion of fuel oil, since the flame needs sufficient space within the diameter so that the atomized fuel does not "collide" with the relatively cold wall of the cylindrical combustion chamber and prevent its proper combustion.

This situation is not corrected by the atomization angle, since for a certain combustion "power", this diameter must have a minimum.

Other ways to express boiler steam output: We can say that a boiler's steam output is 40 kg/h of steam per m² of heating surface.

This means the boiler's steam capacity in kg is given by the expression: kg/h/m² x heating surface = kg of steam per hour

We must specify the pressure, steam and water temperatures to be used, or the equivalent kg of steam at 100°C (212°F).

In older boilers, this value was around 15-20 kg/h/m², while currently it is more than 50-55 kg/h/m² in fire-tube boilers.

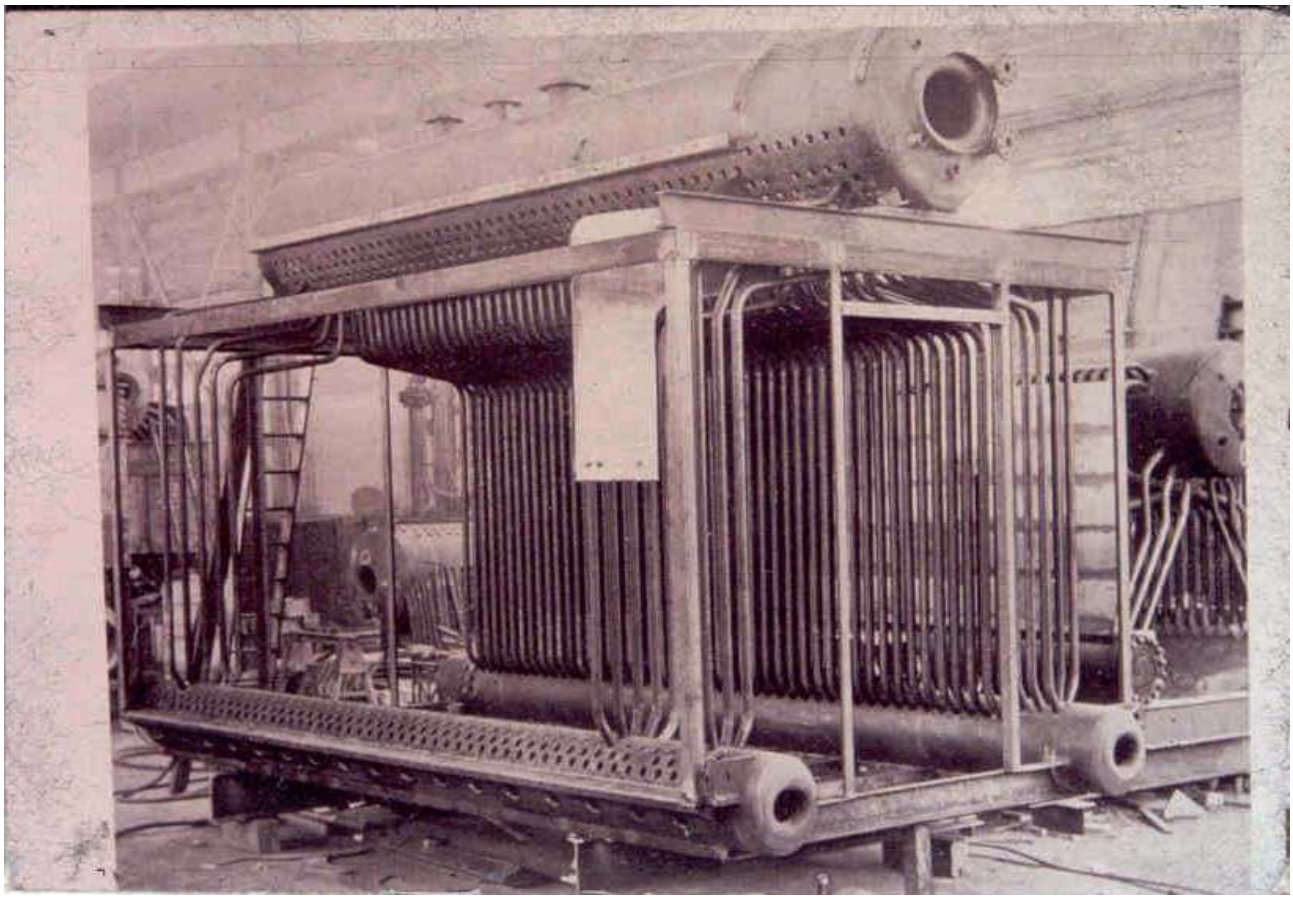
The United States (USA) expresses steaming capacity in "boiler horsepower" (BHP): 1 "horsepower" is equivalent to 33,475 BTU/hour or 8,502 kcal/hour (approximately 30 lbs. of steam at 70 PSI gauge with feedwater at 100°F (37.7°C)).

That is, approximately 13.6 kg of steam at a pressure of 4.9 kg/cm² (69.7 PSI gauge with feedwater at 37.7°C (100°F).

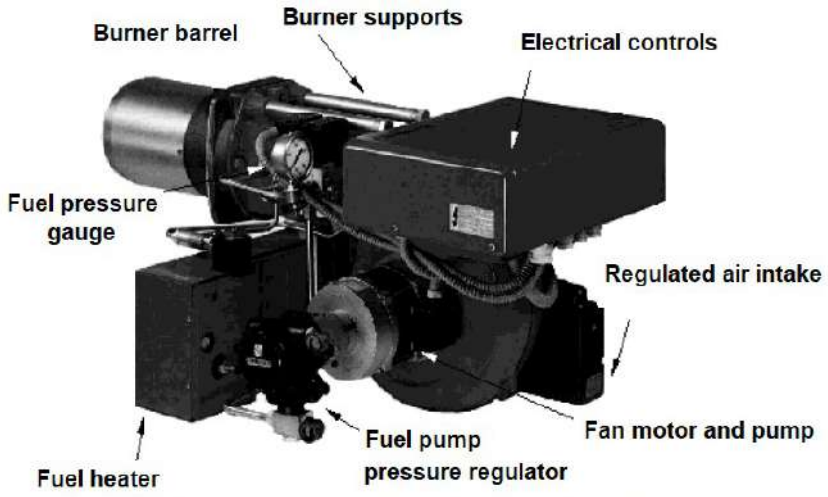
This average expression in kg/m², which refers to the total heating surface, should not be confused with the maximum permissible limits for households, which also refer to surface areas.

Currently, it is very common to express boiler capacity in kWh (kilowatt-hours, 1 kWh = 860 kcal), both combustion capacity and steam production capacity.

Joules, or better yet MJ (megajoules), are also used. Remember that a mega is 1,000,000 times a second, and that a joule is equivalent to a watt, a unit of measurement per second. Converting this to kWh, 3.6 MJ is equivalent to 3.6 MJ, since one kWh is equal to 860 kcal, or 1 MJ = 860/3.6 = 238.9 kcal.



CHAPTER 25: DATA ON BURNERS



MECHANICALLY PRESSURIZED LIQUID FUEL BURNER

Recommended temperatures for different types of atomization:

Mechanical atomization.....approx. 135°C (275°F) to 145°C (293°F) in heavy fuel oil.

approx. 115°C (239°F) to 125°C (257°F) in heating fuel oil.

Steam atomization.....approx. 95°C (203°F) to 110°C (230°F) in heavy fuel oil.

approx. 75°C (167°F) to 90°C (194°F) in heating fuel oil.

Air atomization.....approx. 110°C (230°F) to 125°C (275°F) in heavy fuel oil.

approx. 90°C (194°F) to 115°C (239°F) in Heating Oil.

Cup Atomization:..... approx. 90°C (194°F) to 100°C (212°F) in Heavy Oil.

Approx. 60°C (140°F) to 70°C (158°F) in Heating Oil.

These values vary according to local burner conditions (burner type, furnace, operation, etc.).

Viscosity values (approx.) for atomization according to burner type:
SSU = Seybolt Universal Seconds

300-150 SSU: Large steam atomizing burners.

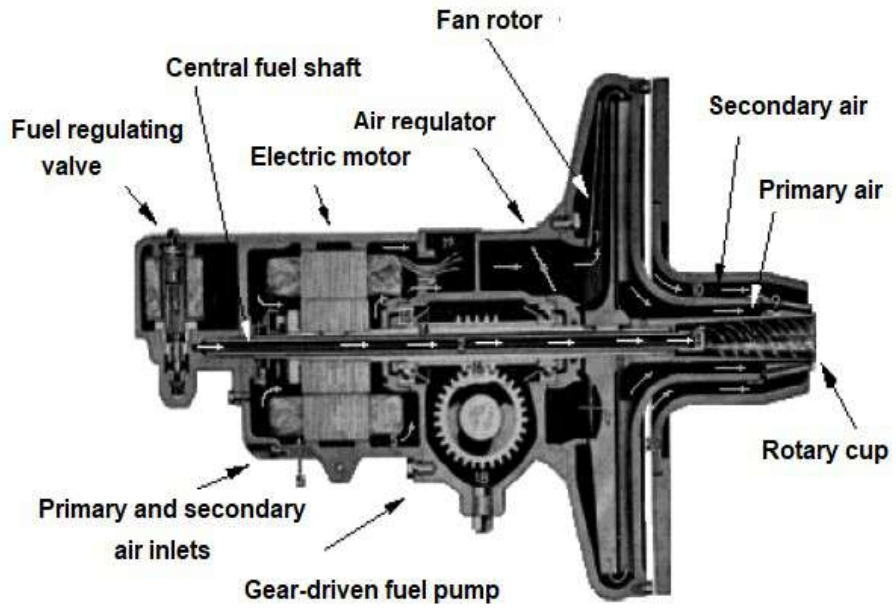
100-150 SSU: Small steam or air atomizing burners, rotary cups.

100-70 SSU: Large mechanical atomizing burners.

70-36 SSU: Medium and small mechanical atomizing burners with nozzles (preferably for heavy oil).

With standard nozzles, fuel oil operates at very high temperatures, and atomization is generally poor.

Up to 36 SSU: Mechanical atomization with standard nozzles (heating fuel oil, diesel oil, and gas oil).



ROTARY CUP BURNER FOR LIQUID FUELS

Atomizing nozzles or nozzles (in mechanical atomization).

Their characteristics are generally expressed as follows:

Capacity

in common nozzles (mechanical atomization burners) is expressed in USG.

Example:
10 USG, this means the hourly capacity in US gallons (3.78 liters per gallon), but at a pressure of 100 PSI (pounds per square inch) (approximately 7 kg/cm²) with No. 2 fuel oil at 60°F (equivalent to diesel fuel at 15.5°C).

This capacity then varies according to the fuel pressure, temperature, and type of fuel in the burner.

Contrary to what one might think, with more viscous fuels, despite common sense suggesting they would pass through with greater difficulty (per kg/h), the same nozzle at the same pressure passes more heavy fuel oil (kg/h) than heating oil, diesel, or gas oil (kg/h).

In other burners, the nozzles (flashes) and their atomization (turbulence) chambers are indicated by a number and letters, which each manufacturer specifies in their regulations.

The capacities of the atomizing nozzles vary in relation to the square root of the pressures: if at pressure P1 the burner has a flow rate of V1 U.S.G., at pressure P2 it will be V2 = V1 x Square root of P2/P1.

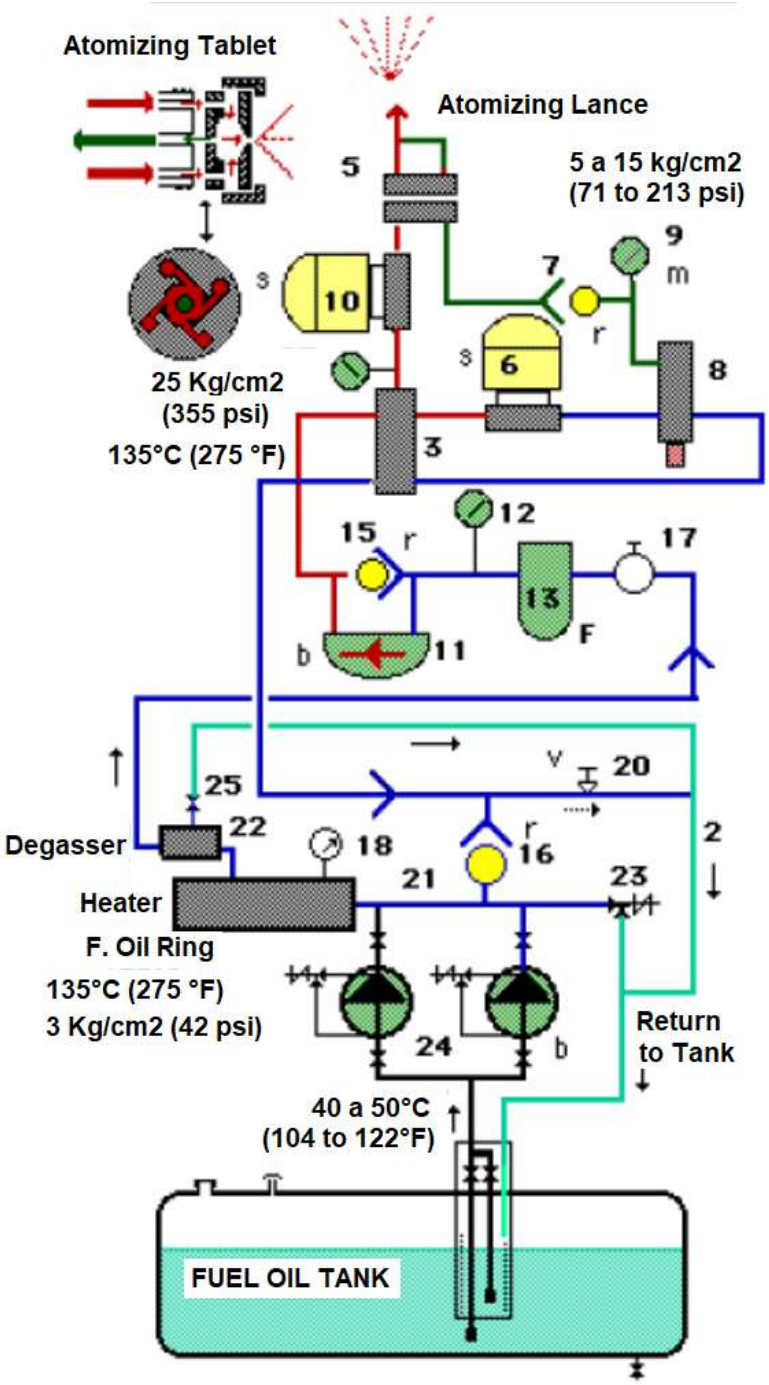
Nozzle type according to fuel:

There are special nozzles for heavy fuels. They are marked with the letters H.O. (Heavy Oil) and a number, which indicates the most suitable operating pressure for that nozzle. Common nozzles do not have this pressure rating.

Example:

H.O. 430 is a nozzle for fuel oil that should operate at 430 PSI (pounds per square inch) or 30 kg/cm².

The standard values are H.O. 200 and 430.
These nozzles are made with "harder" materials to work with fuels containing more "impurities."



10 6 solenoids

8 return regulator

3 safety relief and cut-off valve

11 high-pressure pump

24 low-pressure pumps

7 15 16 check valve

20 manual return regulator

5 lance coupling

23 relief valve

22 degasser

9 16 25 pressure gauges

25 gas return valve

13 filter

17 valve

These nozzles are tested at the marked pressure (200 PSI, 430 PSI, etc. lb/#) with a "heavy" fuel at a viscosity of 66-77 SSU, with an API gravity of 34-36 at 60°F (15.5°C).

They are tested to verify their flow rate at the working pressure indicated in the tables, although the flow rate printed on the U.S.G. --- is the nominal flow rate tested at 100 pounds per square inch (7 kg/cm²), with a viscosity of 34-36 SSU and an API gravity between 32-38 at 60°F (15.5°C), corresponding to a No. 2 fuel oil (Gas Oil).

The atomizing pads, formed by flat surfaces between the swirl chamber and the pad, must be ground periodically (using fine grinding compound and, alternatively, a marble slab or thick, flat glass) to ensure that both surfaces make perfect contact (testing with Prussian blue).

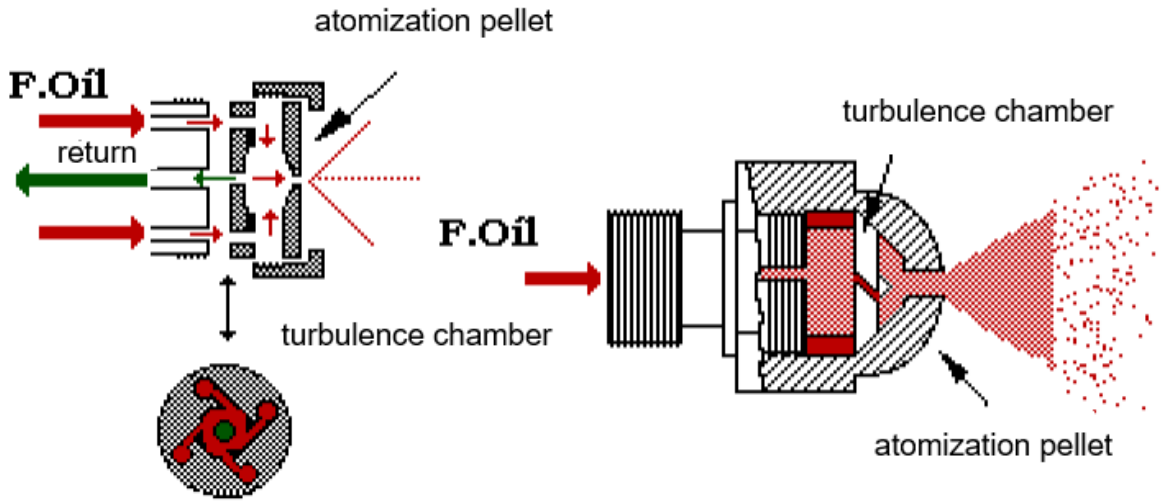
If these flat surfaces do not seat correctly, fuel leaks outside the grooves in the swirl chamber will prevent the proper rotational action, resulting in inadequate atomization.

Furthermore, the material used to manufacture these components must be refractory steel to prevent deformation at the high temperatures they endure (flat surfaces tend to deform at high temperatures but flatten again at low temperatures, which "deceives" the operator when testing them with Prussian blue).

This is the sketch on the left of the following drawing (a mechanical atomizing nozzle with flow control via fuel return, designed to maintain the fuel velocity in the torsion chamber, where the fuel acquires the centrifugal spin that allows it to exit through the nozzle's orifice in atomized form.

Each "droplet" travels in a straight line; only the primary and secondary air change trajectory.

The flow rate varies due to the return flow, which lowers the atomization pressure but not the atomization quality, up to a certain limit).



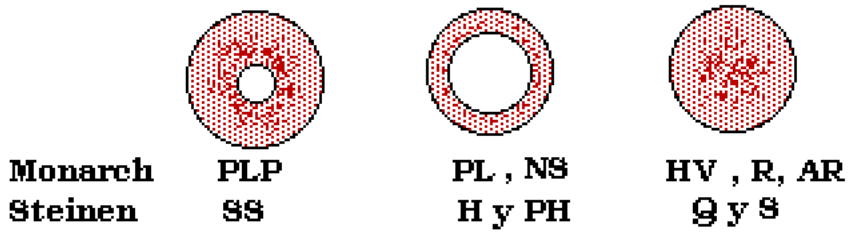
Burner nozzle and turbulence chamber. Most common burner nozzle.

Spray cone shape: Nozzles are designed so that the atomization cone shape is suitable for the type of furnace in which they will be used. These shapes can be a simple cone, a cone with a higher concentration of fuel in the center, a cone with a hollow center, a ring, etc.

The shape is indicated by letters that each manufacturer uses according to their product: for example: R (center-loaded cone), NS (hollow center cone), AR (slightly less center-loaded cone), S (highly center-loaded cone), H (even ring), PH (thin ring), SS (thick ring), Q (even cone), etc., all related to the manufacturer's code.

The atomization angle is the angle formed by the cone; generally, the heavier the fuel, the greater the atomization angle required.

When ordering the nozzle, the following is indicated: The brand (Steinen, Monarch, etc.), the capacity in U.S.G. (number), the type of atomization cone (R or other) and the atomization angle (the most common are 45º, 60º, 90º, etc.) and if it is H.O. (Heavy Oil, i.e., for heavy fuel) plus the working pressure a number (420, 300, 200 lb/#).



SHAPE OF THE ATOMIZATION CONE ACCORDING TO DESIGNATIONS
Working pressures in the most common burners (with mechanical nozzles).

With heavy fuel oil, the working pressure at the nozzle should be high, as higher pressure generally results in better atomization of a heavy fuel.

If the nozzle doesn't specify a working pressure, a normal pressure can be between 22 kg/cm² and 30 kg/cm², slightly lower for heating fuel oil.

With diesel and gas oil, pressures tend to be lower; 7 to 15 kg/cm² is generally sufficient. Be careful not to increase the pressure too much, as this increases the fuel flow and can lead to over-ignition.

In burners with steam or compressed air atomization, the fuel pressure at the nozzle is generally lower, reaching a maximum of 15 kg/cm² (213 PSI), with a typical range between 4 kg/cm² (47 PSI) and 12 kg/cm² (170 PSI).

The atomizing steam pressure depends on the nozzle type. In some, it is slightly higher than the fuel pressure, while in others, it is fixed at a "purge" pressure, which might be, for example, between 2.5 kg/cm² (35.5 PSI) and 3.5 kg/cm² (49.8 PSI).

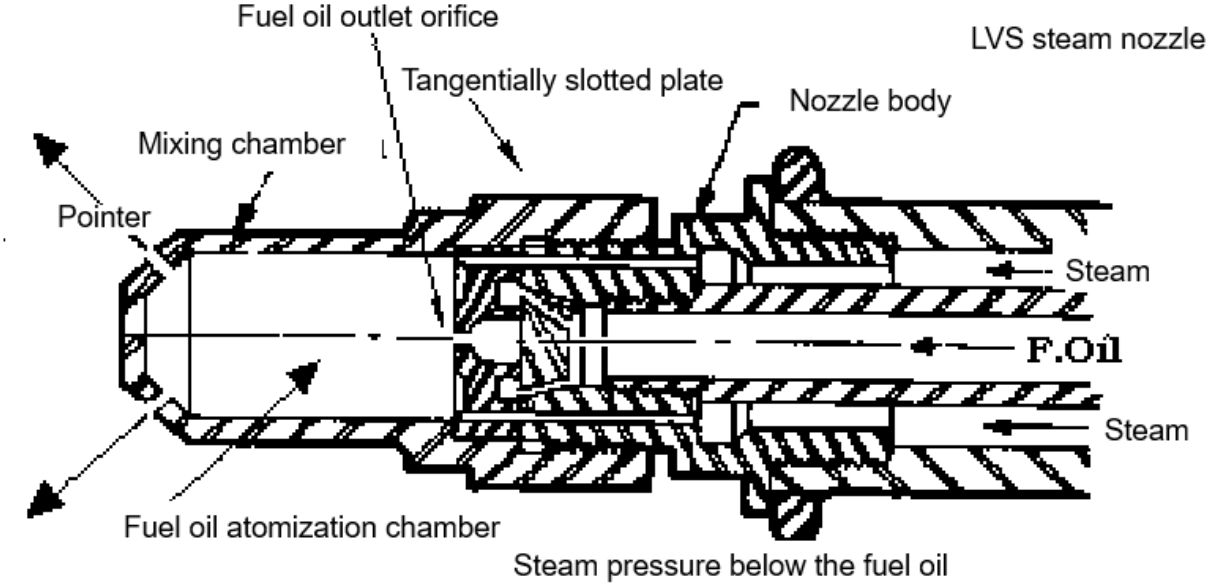
Remember that this steam must be dry and saturated; it must not contain any water droplets or water at all. A good water separator must be installed before the steam pressure regulator enters the burner.

One way to know if we are overheating is to measure the chimney temperature; if the gases are hotter than indicated by the manufacturer or by the type of boiler, we are overheating (unless the boiler is dirty with soot or encrusted, or a gas partition is "perforated" in "short-circuit").

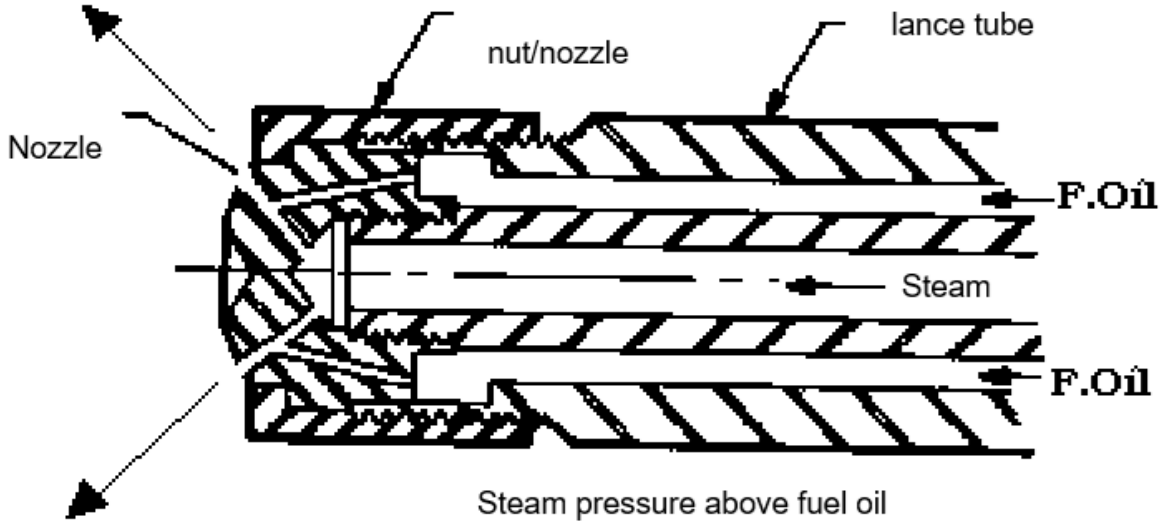
STEAM ATOMIZATION, MOST COMMON LANCES:

The LVS steam atomizing lance (or possibly air) uses steam to "carry" the atomized fuel oil into a chamber (where simple mechanical atomization occurs). Therefore, the steam does not need to be at a pressure higher than the fuel oil pressure (generally between 2 and 3 kg/cm²).

This type of lance can operate with compressed air, as in the case of startup (although a smaller capacity lance or a mechanical atomizing lance is usually used).



The Y-Jet steam atomizing lance, using steam at a higher pressure than the fuel oil, "carries" the fuel oil and atomizes it directly in the combustion chamber.



Y-Jet steam nozzle

The steam pressure is generally 1.5 to 2 kg/cm² above the fuel oil pressure, which varies between 3 and 12 kg/cm².

This system does not function properly with compressed air. For this reason, a mechanical atomizing lance will be used for startup with a cold boiler.

CHAPTER 26: SUGGESTIONS FOR SAVING FUEL IN STEAM-GENERATING PLANTS: POINTS TO CONSIDER

1- Lower the operating steam pressure in the boiler (or the water temperature in a hot water boiler) to the lowest possible level that still allows the steam to be used in the process.

Note that in some cases, lowering the boiler pressure may require reducing the maximum steam generation capacity, as this can disrupt internal circulation or introduce water carryover into the steam.

2- Use the burner (even with wood) as modulated as possible: in oil-fired boilers, use modulating burners or burners with alternating flames, regulating the lowest flame so that it doesn't go out as much as possible and ensuring that the highest flames don't exceed the maximum steam consumption (the response should be smooth).

When using wood, load it in short bursts, and regulate the air supply to prevent the boiler from shutting down due to high pressure, so that combustion matches steam production.

3- Place a thermometer in the chimney and try to keep the temperature as low as possible, periodically cleaning the heat transfer surfaces, especially the soot (or ash) on the hot gas side.

On the water side: perform a good chemical treatment, clean the sludge periodically, and keep the heat transfer surfaces free of scale by performing chemical and/or mechanical cleaning.

This temperature will be influenced by the combustion percentage, excess air, and operating pressure.

4- Keep excess combustion air to the minimum necessary

To prevent heating air that isn't being consumed), while still ensuring complete combustion.

In fuel oil, maintain a light caramel-colored smoke in the chimney, with an orange flame and slightly darker tips, indicating complete combustion before reaching the flue (CO_2 between 13% and 15%).

With firewood, smoke doesn't indicate combustion conditions, and flame observation is only feasible in direct combustion: the flame should reach halfway up the flue pipe, always filling the flue opening with flame (in tubular stoves).

In gas generators and gas stoves, flame observation is not a reliable guide; it's preferable to measure the gases.

In wood-burning stoves, the recommended CO2 level is between 14% and 16%, and O2 between 3.5% and 5.5%, since higher CO2 levels are generally accompanied by the presence of unburned gases.

Verify that the stove is on the excess air side by checking for the absence of CO (carbon monoxide).

Alternatively, measure the %CO2 and %O2 (oxygen) and use an Ostwald triangle.

In natural gas, observing the flame is difficult.

Try to measure the CO2% (around 10.5%) or the O2% (around 3%), but ensure there is no CO (or a maximum of 400 ppm).

5- Check the chimney for unburned gas leaks.

The presence of unburned gases is very common in wood and gas combustion, due to combustion problems or insufficient air.

In these cases, only measurement allows for detection.

This loss can be significant (up to 5-7% for every 1% of CO in chimney gases).

6- Improve fuel conditions.

Especially with firewood, try to burn wood with a low moisture content (22% to 25%) and in good storage conditions (not too old, rotten, etc.). It's worthwhile to maintain the log storage area.

7- Seal all air leaks that may enter the boiler but are not part of the combustion process.

Using a candle flame or a kerosene or diesel burner, check all the gaskets on the covers of the flue boxes or masonry to find air leaks (the candle flame is drawn towards the leak).

Seal these leaks with asbestos rope (a questionable material) or other suitable material.

These air leaks heat up and carry the heat through the chimney, appearing as excess air.

8- Adjust the negative pressure in the combustion chamber to the lowest possible value (in boilers with negative pressure).

Place a U-tube filled with water (glass, plastic, etc.) in the combustion chamber to measure the negative pressure.

The greater the negative pressure, the greater the air losses due to air entering from outside and through the combustion zone.

9- Improve the insulation of the boiler and its accessories.

Almost everything can be insulated to a certain extent. Asbestos is banned in most parts of the world today.

Other approved insulating materials exist that are safe for human health and the environment.

There are areas that should not be over-insulated, as this could lead to very high internal temperatures and potentially cause burns: refractory firebox walls, lids in areas with very hot gases, etc.

10- Control the amount of purge blowdown and use continuous blowdown, extracting the heat in a heat exchanger.

A percentage of continuous purge blowdown is always necessary.

Bottom and level purge blowdowns are necessary for safety and sludge removal.

Heat recovery from these purge blowdowns is difficult, but all the purging of dissolved salts can be done through continuous purge blowdown, easily extracting the heat in a heat exchanger (to heat the makeup water or for other purposes).

11- Recover as much return condensate as possible.

It is pure water, which reduces the need for blowdown.

It is hot water, requiring less heat to vaporize (if necessary, increase the height of the feed tank to prevent pump slippage - cavitation).

12- Recover flash steam.

Every kilogram of flash steam recovered is one kilogram less steam that the boiler needs to generate.

13- Insulate steam pipes, condensate pipes, fittings, and equipment that require heating.

The insulation must be of adequate quality and thickness, as well as the finish of its protective covering (sheet metal, fiberglass, material, etc.).

Fittings such as valves, regulators, etc., are areas of significant heat loss. They can be insulated with insulation blankets that are removed during repairs or maintenance.

The cheapest insulation is not necessarily the most economical.

14-Reduce the temperature and timing of processes as much as possible.

This will result in lower steam consumption.

15-Install control instruments: thermometers, pressure gauges, flow meters, etc.

These will allow for visual monitoring and the setting of limits for each case. (*NOTE)

16-Automate where possible.

Automation more effectively controls these usage limits for energy management, and with proper adjustment, allows for energy use tailored to the process needs.

17- Verify that the steam traps are appropriate and functioning correctly.

Steam traps should be carefully considered; the cheapest ones are sometimes the most expensive to run.

Each trap has a more convenient use, but nowadays the cost of use should be considered more than the initial cost.

Maintenance of the traps affects steam consumption. Some traps consume energy when operating: they are "wasteful."

18- Install condensate sight glasses on the traps.

Traps should be checked daily using sight glasses. If sight glasses are not installed, a check can be performed with a surface thermometer or a trap tester (acoustic or thermal).

19- Heat Exchangers.

These must be suitable for the intended use, as excessive time to achieve the desired effect, condensate loss, the need for higher pressures, etc., lead to greater losses.

20- The Installation Itself.

Pipes with inadequate layouts, unforeseen drops, excessive flat bars, etc., are also causes of heat loss.

21- Boiler Makeup Water Quality.

We should look for water with the lowest salt content, as this allows for less purge blowdown (saving heat and water), lower treatment costs (salt in the softener, internal chemicals), and fewer steam problems (due to salt decomposition).

Surface water (generally from OSE in Uruguay) is usually better than well water (which may seem cheaper to use).

22-Heat Recovery Systems.

Installing heat recovery systems can be an effective way to save energy: excess temperature in chimneys, wastewater, equipment vents, hot air or gas extraction systems, etc.

23-Operating Methods.

Whenever possible, operate with one boiler instead of two, two instead of three, etc. Keep the boiler operating at approximately 80% of its capacity, etc.

24-Design.

Many pieces of equipment (boilers, heat exchangers, etc.) were designed with criteria different from current standards (materials, construction, fuel cost, etc.). Sometimes, a new boiler or new piece of equipment pays for itself in just a few months through fuel savings.

25- Have the necessary handheld instruments for inspection.

Combustion gas meters, portable thermometers for immersion, surface use, etc., with training for the personnel involved. (*NOTE)

26- Training and awareness.

Raising awareness is fundamental to achieving energy savings, and for this, people must be trained: given the necessary knowledge and appropriate practical training.

In some cases, this may involve hiring people from outside the company (sometimes "no one is a prophet in their own land") with recognized expertise in the subject, who possess teaching skills and can capture people's attention.

(*NOTE) All instruments (analog/needle or digital/digital), in order for their readings to be considered "reliable measurements," must be periodically checked against a reference standard instrument (either owned by the industry o seller itself or from an independent calibration laboratory). Generally, low-cost instruments have significant precision/resolution and uncertainty, typically 10 to 20% deviation/error.

Expensive international-class or industrial-grade instruments exhibit precision and uncertainty on the order of 1 to 2%. Only commercial-grade measuring equipment used for billing purposes offers resolution/precision and uncertainties of Class 0.5 or Class 0.2. (0.2 to 0.5 % deviatio/error when checked to a standard reference laboratory instrument.

And always remember the safety of the personnel operating and maintaining the boiler. Use PPE correctly, in good condition, and up-to-date (not obsolete).

Gone are the days of working while committing unsafe acts.

Human life comes first; the equipment can be repaired.

Stoker Boiler Handbook 2011, C.W.T. – CHAPTER END: C.W.T. C.V.

Carlos Walter Thomasset Curriculum Vitae

Carlos Walter Thomasset Baister, born in 1940 (Argentina), Uruguayan by choice (Uruguayan father and English mother), Law 16.021. He began his studies in Argentina, then in Uruguay. He entered the Uruguayan Naval Academy in 1959, competing to study as a member of the CIME Corps (Engineering Corps in Machinery and Electricity), a five-year residential program, with revalidation as a Merchant Marine Engineer.

He served in the Navy until 1972, in various departments, as a technician in subjects specific to the corps, and as a professor at the Naval Academy in Electrotechnics for CIME and Merchant Marine Engineers, as well as at the Navy's School of Specialties on Montevideo Hill (seaman training).

In 1972 he moved into industry, winning a competition in Buenos Aires, for Head of Engineering at a Beet Sugar Factory in the Litoral (with 100 tons/hour of steam generation and with 5,500 kWh electric turbo generators, working for 5 years), replacing the French Engineers from the firm Begain (France).

He then began providing advisory and consulting services (1978) to various companies throughout the country (including boiler factories). The need to maintain optimal steam generator operation led him to work across the entire field (mechanical, thermodynamic, electrical, electronic, pneumatic, automation in general, chemical services, combustion). The "boiler" environment was second nature to him, as it was the era of "steamships" (ships propelled by steam, and at sea there were no workshops or support services like those on land).

Currently, in 2011 (more than 50 years experience, after having been involved with boilers since 1959), he provides consulting services to more than 50 companies on boilers, chemical treatments (through training for boiler operators), and combustion control (now celebrating 38 years of work in the industry).

These manuals are intended solely as a contribution to the development of boiler operators, key players in a country's energy use, who should have a PROFESSIONAL BOILER OPERATORS ASSOCIATION to ensure representation at boiler-related events, improve boiler management, and benefit from mutual support.

“PEQUEÑO MANUAL DEL FOGUISTA 2011, C.W.T.”
STOKER BOILER HANDBOOK 2011 C.W.T.

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